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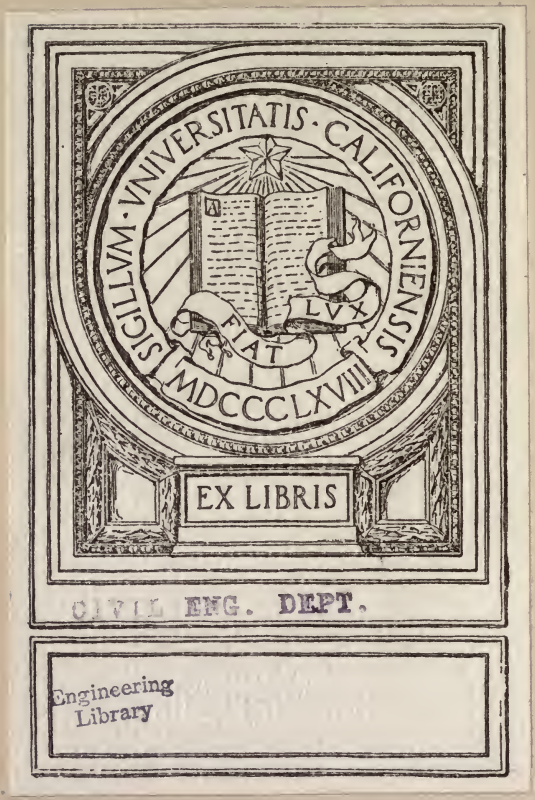

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CHEMISTRY AND CIVILIZATION

LECTURES DELIVERED
UNDER THE
RICHARD B. WESTBROOK FREE LECTURESHIP FOUNDATIONS
AT THE
WAGNER FREE INSTITUTE OF SCIENCE
PHILADELPHIA

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CHEMISTRY AND CIVILIZATION

BY

ALLERTON S. CUSHMAN, A.M., PH.D.

Director, Institute of Industrial Research, Inc., Washington, D. C., Ex-Lieut.-Col. Ordnance Department, U. S. A.

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TO
MY WIFE

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PREFACE

THE attempt to present in a few brief chapters a general view of all that chemistry has done, is doing, and hopes to accomplish for mankind in the future, has been no easy task. At best the author has been able only to sketch in the high lights and deep shadows of the pictures. The effort has been made to produce at least a readable story of chemistry, that may hope to interest even those who have not heretofore given attention to the subject as it affects their own lives. In spite of this effort, several nonchemical friends who have been kind enough to read the manuscript or patient enough to attend the lectures have remarked: "I enjoyed it very much, though I must confess I did not understand a great deal of it." If the writer has indeed succeeded in presenting the subject in a manner which will produce enjoyment and instruction even when the understanding is incomplete, surely the effort has not been entirely in vain.

Much of the subject matter discussed has been given before, as for instance by Geoffrey Martin in his *Triumphs and Wonders of Modern Chemistry*, and by Professor Sir William Tilden in his *Chemical Discovery and Invention in the Twentieth Century*. To both of these authors the writer is much indebted. Perhaps the best excuse for the present volume lies in the fact that other writers have not been at so much pains to link up the present and future of this branch of science with its historical past. There can be no doubt that the destiny of the human race is deeply

involved with the history and future developments of chemistry, and yet the ordinarily well educated or well informed person, the "man in the street," has been wont to look upon this branch of study as a species of necromancy, at best a medley of evil odors or, in plain Anglo-Saxon, "stinks," which it is quite outside his province or possibility of understanding. The business man at the head of industrial operations which make direct use of the marvels of chemistry is too often heard to say: "I don't know anything about chemistry and I don't want to know anything about it; I hire chemists." That this is the wrong and unprogressive attitude is obvious, just as much as though a farmer should say: "I don't know anything about farming; I hire farmers." As a matter of fact, the general or unspecialized study of chemistry is no more difficult than that of shorthand stenography which indeed in some respects it resembles. Thousands and thousands of our young men and girls acquire a working knowledge of stenography every year, even if comparatively few become really experts in their line. Chemistry as a study enjoys and is founded on one of the most simple and exact systems of symbolic shorthand ever devised for any purpose, for it is at one and the same time descriptive and mathematically quantitative. The world needs more chemists and it is a field of labor and reward in which there is no reason why women should not work side by side with men.

If the author should by means of this volume succeed in attracting more young people to the study of this fascinating subject, his efforts will not have been wasted.

Washington, D. C.,
April, 1920.

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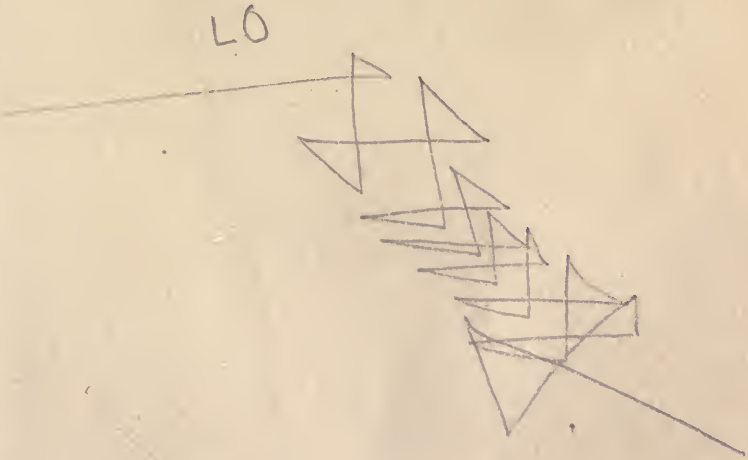


CHEMISTRY AND CIVILIZATION

CHEMISTRY AND CIVILIZATION

CHAPTER I

CHEMISTRY IN THE PAST

AGES before Man appeared on this planet, chemistry was at work preparing a suitable environment for his reception. Indeed, the clashing atoms were deforming and reforming their combinations through countless eons before any living thing appeared to take cognizance of the great cosmic drama. Then at some dim time in the cooling process of the world's formation, the miracle of miracles occurred, a lowly organic germ or group of germs came into being. Undoubtedly these primordial cells grew, divided, multiplied and differentiated, and the chemistry of the life process was staged with all the triumphs and marvels which were to come. A great evolutionist has said that given the beginning of the lowliest cell of living protoplasm, Man was the inevitable predestined result. Darwin says in the *Origin of Species* "I should infer from analogy that probably all the organic beings which have ever lived on this earth have descended from some one primordial form, into which life was first breathed." Later Whitney and Wadsworth [1]

[1] *The Azoic System*, p. 546.

state: "It is now clearly established that there was a time when life was represented by a few forms, which were essentially the same all over the globe." It is not generally realized that the chemical processes that brought these primordial forms into being and made possible their evolution were laying the foundation stones on which the civilization and industry of man is builded. Let us pursue this line of thought for a moment. Countless myriads of lowly calcareous animalculæ lived, absorbed their increment of lime from primitive sea waters, died and shed their shells throughout long geological periods to form the great limestone strata of the earth's crust. With limestone man smelts iron and the other metals, and with the metals he harnesses the energy of steam and electricity. From the casts of these primeval forms man makes Portland cement which enables him to mould his building stone in the place he wants it, so that in a few hours it attains the same condition of solidity and durability as the rocks Nature took a million years in the making. With limestone man fixes the nitrogen of the air and therewith provides the food for his crops that in turn must feed him throughout all time to come. On limestone man founds his great alkali industry which in turn makes possible the manufacture of glass, textiles, soap, and above all paper without which the art of printing and our entire system of education would never have become possible.

Contemporarily with the animalculæ, the primeval forests flourished and decayed so that eventually the coal measures were laid down. No living creature in the scale from the diatom to the dinosaur was ever interested in coal, but one day an animal shaped like a man discovered fire; industrial chemistry began on that day. Prehistoric man practiced

the arts of ceramics and metallurgy, and none are more dependent on obscure chemical actions and reactions.[2]

Geoffrey Martin [3] in his interesting work on *The Triumphs of Modern Chemistry* introduces his subject as follows:

The endless circulation of matter in the universe is perhaps one of the most wonderful facts with which chemistry has to deal. It is this endless change which causes the history of the most common and insignificant objects about us to be more astonishing than any fairy tale. What a won-

[2] In order to lighten the somewhat profound phase of the subject under discussion, I venture to follow the example of Prof. Sir William Tilden by quoting the witty and humorous lines of Constance Naden whose untimely death in 1889 deprived science of an eminent woman worker.

"We were a soft Amoeba
In ages past and gone,
Ere you were Queen of Sheba
And I King Solomon.

Unorganed, undivided,
We lived in happy sloth,
And all that you did I did,
One dinner nourished both:

Till you incurred the odium
Of fission and divorce—
A severed pseudopodium
You strayed your lonely course.

When next we met together
Our cycles to fulfil,
Each was a bag of leather,
With stomach and with gill.

But our Ascidian morals
Recalled that old mischance,
And we avoided quarrels
By separate maintenance.

Long ages passed—our wishes
Were fetterless and free,
For we were jolly fishes
A-swimming in the sea.

We roamed by groves of coral,
We watched the youngsters play,
The memory and the moral
Had vanished quite away.

Next each became a reptile,
With fangs to sting and slay:
No wiser ever crept, I'll
Assert, deny who may.

But now, disdaining trammels
Of scale and limbless coil,
Through every grade of mammals
We passed with upward toil.

Till anthropoid and wary
Appeared the parent ape,
And soon we grew less hairy,
And soon began to drape.

So from that soft Amoeba
In ages past and gone,
You've grown the Queen of Sheba,
And I, King Solomon."

(*A Modern Apostle.* Kegan Paul, Trench and Co., 1887.)

[3] *Triumphs and Wonders of Modern Chemistry.* Van Nostrand & Co., 1911.

derful story could be told, for example, of the material which forms our bodies! It came into existence in the immense depths of space millions upon millions of years ago, and reached our earth. Perhaps it fell upon the earth in a fiery meteorite, or perhaps it merely joined the huge fire mist from which our solid earth condensed. Since then it has run round age after age in an endless circle of change. First it formed part of that vast primeval atmosphere which surrounded the globe, and blew in mighty winds around our planet; then it was absorbed into the body of some humble living being, and when this being died and its body decayed, the matter passed into the rich mother earth. Thence it passed into some plant by means of its roots; and from the plant it passed by being devoured into the body of some animal; and from the animal again it passed to earth and thence to plants and animals again; and so on through an endless cycle of change, coursing through the bodies of innumerable multitudes of living forms, which stretch far back in a dim unending vista into the depths of time. Finally it reached man; yes the very atoms which thrill and flash in our brains and muscles once formed part of a living plant or animal millions of years ago, and will again form part of a living plant or animal millions of years hence. In some form or other the matter which now forms our bodies will exist long after the whole present order of creation has passed away; indeed it may well yet blow in the winds of worlds as yet unborn and thrill in forms of life not yet evolved.

As Hamlet pessimistically soliloquizes:

To what base uses we may return, Horatio!
Why may not imagination trace the noble dust of Alexander till he find it stopping a bung hole?
Alexander died, Alexander was buried,
Alexander returneth into dust: the dust is earth; of earth we make loam; and why of that loam, whereto he was converted, might they not stop a beer barrel?
Imperious Cæsar, dead and turned to clay,
Might stop a hole to keep the wind away.

All this is transcendental chemistry, if you please, though no one can deny its literal truth. In the light of very modern research connected with the discovery of radium, it may well be doubted if matter is as really indestructible as the so-called law of conservation provides for, but whatever new discoveries the future may have in store, there can be little doubt of the essential immortality of matter. In other words, the atom, the unit of matter, may change, but it cannot be *put out of existence.*

No review of the history of chemistry, however brief, is complete without some reference to the alchemists and dreamers who kept chemistry alive through the dark ages. An early edition of the Encyclopedia Brittanica spoke of alchemy as the sickly but imaginative infancy through which modern chemistry had to pass before it attained its majority, or, in other words, became a positive Science. Such a definition does not, however, do justice to the subject, for although alchemy in the popular and narrow sense was mainly concerned with the vain attempts to transmute base metals into gold, there was a deeper if not an esoteric significance connected with this philosophy. In the words of Liebig, one of the great founders of modern chemical research, alchemy was never at any time anything different from chemistry. Nevertheless, there is a wealth of interesting tradition and legend connected with and built about the early origin of the art. Alchemy is spoken of by the earliest writers as the Egyptian art or black magic, and it has been supposed by some etymologists to have derived its name from the word khem, the hieroglyphical designation for the black earth or soil of Egypt. However this may be, the prefix al which was later dropped is of Arabian origin and reminds us that the Arabs were from the earliest beginnings up to the time of the Moorish conquest of Europe active

contributors to the art and science of chemistry which was frowned upon by the Christian dispensation practically to the time of the French Revolution and the fall of the temporal and ecumenical power of the Church.

A mystic legend handed down by Zosimus of Panopolis, an early alchemical writer of the Third Century, relates the strange story that the sons of god who took unto themselves wives of the daughters of men as set forth in the VIth Chapter of Genesis, taught the art to the women and recorded the teaching in a book called Chema. This story is repeated in the book of Enoch, and Tertullion the earliest and after Augustine the greatest of the ancient Church writers, has much to say about the fallen angels who revealed to men the esoteric knowledge of precious metals and stones and the power of herbs and drugs. Another tradition has it that alchemism was founded by the god Hermes Trismegistus (Egyptian Thoth) the master of those who occupied themselves with the study of natural science which became, especially in its esoteric aspect, the Hermetic philosophy. To this day chemists describe a perfectly air-tight vessel as "hermetically sealed."

Space will not permit a detailed history of alchemism, and we must pass on to the real matter of the present subject, the birth and development of modern chemistry. It will suffice to point out that in the early part of the Sixteenth Century Paracelsus, though apparently a quack, nevertheless made the contribution of applying what was then known about chemistry to the preparation and prescription of medicine. J. B. Van Helmont who died in 1644 was the last of the celebrated transmutationists, although J. Price, an Englishman, as late as 1782 claimed to have succeeded in changing mercury into gold, but he is said to have committed suicide when a public demon-

stration resulted in failure. We shall see later on, however, that the transmutation of radium into helium appears to have been proved by twentieth century research, so that the end is not yet.

Having dealt thus briefly with the alchemists, we must now turn our attention to that most interesting interim in the development of modern chemistry comprised in the period of the Phlogistonists. Robert Boyle (1627-1691) was the seventh son and fourteenth child of Richard Boyle, the great Earl of Cork. Educated at Eton College, and on the continent, this young scion of the Irish nobility in spite of great inheritances in landed estates in Ireland and England early turned his attention to study and scientific research, and soon became one of the most distinguished natural philosophers of all time. Boyle surrounded himself with a band of scientific inquirers known as the "Invisible College," who devoted themselves to the cultivation of the new philosophy. We must remember that we are now speaking of a time when among others such great men as Isaac Newton (1642-1727), Leibnitz (1646-1716), G. E. Stahl (1660-1734), and Robert Boyle (1627-1691) were contemporary. These philosophers knew that the earth was surrounded by an atmosphere of air but they were in total ignorance of the nature of this air or of its principal properties. Oxygen and nitrogen had not been discovered, nor were there any reasons to suspect the compound nature of the atmosphere. The discovery of oxygen was not to come until 1774, as we shall presently relate, although, curiously enough, the more inert and difficultly recognizable nitrogen was isolated by Rutherford two years earlier. It was known in the seventeenth century, however, that when certain bodies were heated or calcined in the presence of air, they lost something, while other bodies gained something in substance and weight.

For instance, if we calcine a volume of charcoal powder, it continues to lose substance until it practically entirely disappears. If, on the other hand, we calcine a mass of iron filings it increases in volume and weight, and changes from the metallic condition to a rouge. If we calcine zinc filings, these change to a white powder with an increase in volume and weight. We now know that oxygen joins with the charcoal to form an invisible carbonic oxide gas, and with the metals named to form solid, non-volatile oxides or calces. Today all this is comprehensible to an intelligent child, but the giant intellects of the seventeenth century were completely mystified. It is astonishing that a phenomenon that came to be so simple to the merest tyro of an eighteenth or nineteenth century schoolboy should have puzzled such minds as those of Newton or Boyle; Newton who, lacking mathematical means for expressing his thoughts, invented the calculus, that difficult branch of mathematics that has puzzled and befogged the minds of generations of schoolboys ever since, and Boyle who deduced the laws of gases for all time before the gases themselves were discovered or isolated.

If a body on being heated gained in weight and volume, what was more natural to the seventeenth or even eighteenth century mind than to assume that some substance or material having negative weight or buoyancy was driven out of it? This substance was called phlogiston from the Greek word meaning burnt. The violence or completeness of combustion was proportional to the amount of phlogiston present. A burned metal was a dephlogisticated substance, but it could be phlogisticated again by reheating it with charcoal, which was therefore supposed to be rich in phlogiston. Oxygen was dephlogisticated air and so on through a maze of subtle and perplexing definition and explanation. George Ernst Stahl (1660-1734), the great German physician to

ROBERT BOYLE

the then reigning King of Prussia, was the founder and the great defender of the phlogistic school of chemical philosophy, but it found adherents among such great natural philosophers as Henry Cavendish, Black, and Priestley in England, Scheele, the famous apothecary of Sweden, and many other contemporaries who might be mentioned.

It must not be supposed, however, that all this time a new school of thought was not forming. Boyle himself had early in his career suggested certain experimental inquiries which were being assiduously developed in many parts of the world, and it was not long before the debates between the phlogistonists and the anti-phlogistonists became as vigorous as they were rancorous. Joseph Priestley (1733-1804), famous English chemist and non-conformist minister, was a bitter champion of the phlogistonists and, through he isolated oxygen in 1774 by heating red oxide of mercury in a sealed glass tube by means of a burning glass, he insisted that this gas was dephlogisticated air. He found that a candle burned in the gas with extraordinary brilliance and that living mice subjected to its atmosphere exhibited great vigor. Of the analogy between combustion and respiration—both true phlogistic processes in his view—he had already convinced himself, and his paper before the Royal Society *On Different Kinds of Air* in 1772 showed that living plants are able to restore air that is vitiated by being breathed or by having candles burned in it.

Priestly was a genius and may be forgiven for the obstinacy and narrow-mindedness of his views. We are now approaching the time of the American and French Revolutions, and many wonderful changes for the human race were developing. The sun of the phlogistonists was setting, and Lavoisier, the great Frenchman whose head fell under the guillotine in the days of the Terror, Lavoisier, the real

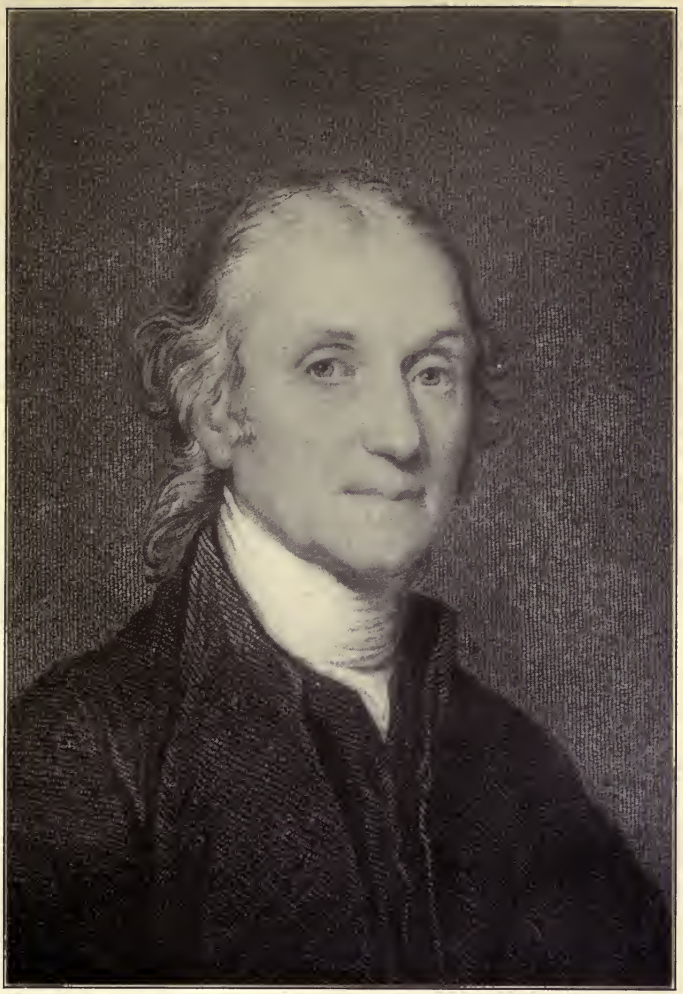
father and founder of modern quantitative chemistry, in that wonderful year 1776 isolated, described, weighed, and named oxygen gas. To quote Lavoisier:

Chemists have turned phlogiston into a vague principle, which consequently adapts itself to all the explanations for which it may be required. Sometimes this principle has weight and sometimes it has not; sometimes it is free fire and sometimes it is fire combined with the earthy element, sometimes it passes through the pores of vessels and sometimes these are impervious to it; it explains both causticity and noncausticity, transparency and opacity, colours and their absence; it is a veritable Proteus changing in form at each instant.

The great Priestley, embittered by debate and disagreement with his contemporaries, emigrated to America in 1794 and settled at Northumberland, Pennsylvania, and there he died ten years later, still an incorrigible phlogistonist. As late as 1800 he wrote to a friend: "I have well considered all that my opponents have advanced, and feel perfectly confident of the ground I stand upon. Though nearly alone, I am under no apprehension of defeat." Thus passed into the limbo of rejected things one of the most fantastic working theories that has ever engaged the attention of scientific men for two whole centuries.

The American Revolution is behind us, and the Declaration of Independence, that great charter of the rights of man, has been written. The French Revolution is about to burst upon the world and upset almost every human system theretofore considered solid. A new system of weights and measures, a new machinery of science makes a sudden entry onto the stage. The immortal Lavoisier has overthrown phlogiston and taught science to weigh and measure. As Liebig later wrote of him:

He discovered no new body, no new property, no natural



JOSEPH PRIESTLEY BY STUART

phenomenon previously unknown; all the facts established by him were the necessary consequences of the labours of those who preceded him. His merit, his immortal glory, consists in this—that he infused into the body of science a new spirit; but all the members of that body were already in existence, and rightly joined together.

From the beginning of the nineteenth century, chemistry entered into the service of man as an exact quantitative science and as a working adjunct of industry. In 1808 John Dalton, the Englishman, revived the atomic theory of the early Greek and Roman philosophers, gave to it accurate quantitative value, and solved in great measure the laws of chemical combination. Dalton announced that matter was composed of atoms which combined in definite proportions to form molecules. This was the beginning of a new system of chemical philosophy which is the basis of the science of modern chemistry which we shall consider more in detail in subsequent pages.

The value of Dalton's generalizations cannot be overestimated, and after their publication in 1808 great contributions to exact knowledge followed in rapid succession. Amongst these may be mentioned Gay-Lussac's observations that gases always combine in simple ratios. For example, one volume of oxygen gas combines with two volumes of hydrogen to form not three but two volumes of steam. One volume of nitrogen combines with three volumes of hydrogen to form not four but two volumes of ammonia gas. The immediate inference was that the Daltonian atom must have parts which enter into combination with parts of other atoms. In other words, this means that nearly all the common gases are composed of molecules consisting of two atoms linked or held together by some mysterious and still unknown affinity which affinity is, however, under certain

conditions overcome, permitting combination with other atoms. Boyle had previously shown that for all practical purposes equal changes in pressure and temperature always occasion equal changes in volume of all gases. Putting this law together with Gay-Lussac's discovery, Avagodro, an Italian philosopher, deduced the wonderful law that equal volumes of all gases at the same temperature and pressure contain exactly the same number of molecules. Although to the layman this may not mean much, it is nevertheless a law on which hangs many of the wonderful deductions and developments of science. In 1860 there prevailed such a confusion of hypotheses as to atoms and molecules that an international scientific conference was held at Karlsruhe to discuss the question. This conference brought about the extension of Avogadro's theory to all substances and permitted the deduction of the atomic weight or combining weight of a non-gasifiable element from the densities of its gasifiable compounds.

From that day to this, chemical philosophy holds that all the matter of the universe is made up of the atoms of some eighty to ninety elements which can combine together in definite proportions by weight to form molecules. Hence every element has a definite combining or atomic weight which is constant and characteristic of each element. Moreover, with a few exceptions, all of these elements that are capable of existing as free gases are composed of double atoms linked or held together to form fixed molecules which can only be torn apart into constituent atoms by the expenditure or release of energy. A compound molecule such as, for example, sulfuric acid (H_2SO_4) is composed of two atoms of hydrogen, one of sulfur, and four of oxygen. These atoms are not held together by chemical affinity in a helter skelter or haphazard fashion, as glass beads would

A TABLE OF THE CHEMICAL ELEMENTS WITH THEIR ATOMIC WEIGHTS

Compiled by The International Committee on Atomic Weights

Name	Symbol	Atomic wt.
Aluminum	Al.	27.1
Antimony (Stibium)	Sb.	120.2
Argon	A.	39.88
Arsenic	As.	74.96
Barium	Ba.	137.37
Bismuth	Bi.	208.0
Boron	B.	11.0
Bromine	Br.	79.92
Cadmium	Cd.	112.40
Caesium	Cs.	132.81
Calcium	Ca.	40.07
Carbon	C.	12.005
Cerium	Ce.	140.25
Chlorine	Cl.	35.46
Chromium	Cr.	52.0
Cobalt	Co.	58.97
Columbium (Niobium)	Cb.	93.1
Copper (Cuprum)	Cu.	63.57
Dysprosium	Dy.	162.5
Erbium	Er.	167.7
Europium	Eu.	152.0
Fluorine	F.	19.0
Gadolinium	Gd.	157.3
Gallium	Ga.	69.9
Germanium	Ge.	72.5
Glucinum (Beryllium)	Gl.	9.1
Gold (Aurum)	Au.	197.2
Helium	He.	4.0
Holmium	Ho.	163.5
Hydrogen	H.	1.008
Indium	In.	114.8
Iodine	I.	126.92
Iridium	Ir.	193.1
Iron (Ferrum)	Fe.	55.84
Krypton	Kr.	82.92
Lanthanum	La.	139.0
Lead (Plumbum)	Pb.	207.20
Lithium	Li.	6.94
Lutecium	Lu.	175.0
Magnesium	Mg.	24.32
Manganese	Mn.	54.93
Mercury (Hydrargyrum)	Hg.	200.6
Molybdenum	Mo.	96.0
Neodymium	Nd.	144.3
Neon	Ne.	20.2
Nickel	Ni.	58.68
Niton	Nt.	222.4
Nitrogen	N.	14.01
Osmium	Os.	190.9
Oxygen	O.	16.00
Palladium	Pd.	106.7
Phosphorus	P.	31.04
Platinum	Pt.	195.2
Potassium (Kalium)	K.	39.10
Praseodymium	Pr.	140.9
Radium	Ra.	226.0
Rhodium	Rh.	102.0
Rubidium	Rb.	85.45
Ruthenium	Ru.	101.7
Samarium	Sa.	150.4
Scandium	Sc.	44.1
Selenium	Se.	79.2
Silicon	Si.	28.3
Silver (Argentum)	Ag.	107.88
Sodium (Natrium)	Na.	23.00
Strontium	Sr.	87.63
Sulphur	S.	32.06
Tantalum	Ta.	181.5
Tellerium	Te.	127.5
Terbium	Tb.	159.2
Thallium	Tl.	204.0
Thorium	Th.	232.4
Thulium	Tn.	168.5
Tin (Stannum)	Sn.	118.7
Titanium	Ti.	48.1
Tungsten (Wolframium)	W.	184.0
Uranium	U.	238.2
Vanadium	V.	51.0
Xenon	Xe.	130.2
Ytterbium (Neoytterbium)	Yb.	173.5
Yttrium	Y.	88.7
Zinc	Zn.	65.37
Zirconium	Zr.	90.6

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arrange themselves in a pill box, but have a definite linkage. We may liken chemical affinity to the gravity linkage of the solar system. Geoffrey Martin [4] presents this idea as follows:

Let us consider a system like the earth and moon. Here the moon revolves around the earth and accompanies it on its journey through space. The moon is thus linked up to the earth, and a chemist would express this relationship by a "constitutional formula" like this: M-E, where E stands for the earth and M for the moon. Now, is this not exactly analogous to the constitutional formula of a simple molecule like that of hydrochloric acid or copper oxide which are expressed by the formulæ H-Cl and Cu-O. The band or link joining the two atoms has here the meaning that the one atom accompanies the other on its journey through space, each atom probably revolving one about the other in the same way that the moon revolves about the earth. Now, let us take a somewhat more complicated system, such as that of earth, moon and sun. Here the earth revolves around the sun and the moon around the earth. The earth is, so to speak, connected or linked to the sun, and the moon to the earth. Hence we could pluck away the moon from the whole system without removing the earth, but if we plucked away the earth, the moon would be removed with it.

Now, this is what we find in the case of the sulphuric acid molecule, for the hydrogen atoms can be removed without removing the oxygen atoms, but the oxygen atoms cannot be removed without removing hydrogen atoms with them.

Just as we removed in succession the moon and the earth from the sun, so chemists remove in succession the different atoms of the molecule in order to elucidate their constitution. The agents which they employ for picking off the atoms are collisions with different sorts of molecules.

[4] Loc. cit., p. 71.

Following this line of interesting though somewhat rough analogy, we must consider the sulphuric acid molecule as a sort of solar system in miniature. It would appear that there must be a central sulfur atom corresponding to the sun, around which all the other atoms rotate. Next come two oxygen atoms revolving one about the other like double stars and the pair rotating about the central sulfur atom, this combination being written SO_2 or $S<^{O}_{O}$. Outside these come two oxygen atoms to each of which a satellite or moon in the shape of a hydrogen atom is provided. The author has included the above analogy at this place in order to show how the mind of the chemist, once furnished with the concepts worked out in the early part of the nineteenth century, occupied itself in the elucidation of the invisible constitution of matter. There will be more to say about this phase of our subject later on.

It will now be necessary to indulge in another analogy in order to make clear some of the great generalizations which were built up around the chemical discoveries of the early part of the nineteenth century. The pianoforte keyboard is made up of eighty-eight notes which have a periodic relationship to each other and which divide into octaves. Groups of these notes have an affinity for one another and when sounded together produce chords and harmonies. When sounded in other groups, there is no blending or combination, and discords result. It has already been pointed out that all the matter of the visible universe is made up of some eighty-odd elements consisting of atoms of definite and characteristic atomic or combining weight. It has also been shown that when brought together in certain groupings these atoms combine to form molecules, whereas in other groupings no combination is possible. The molecules may

therefore be roughly compared to the chords or harmonies of the tonal scale.

John Alexander Newlands (1838-1898) was certainly one of the first, if not the very first, of the nineteenth century chemical philosophers to note the periodicity of the chemical elements. In 1864 he showed that if the elements are arranged in the order of ascending atomic weights, those having consecutive numbers frequently belong to the same group as far as properties are concerned, or they occupy similar positions in different groups, and he pointed out that each eighth element starting from a given one is a sort of repetition of the first, like the eighth note of the musical octave. Newlands Law of Octaves as he enunciated it was at first ignored or treated with ridicule, as too fantastic for serious consideration.

It remained for the great chemists, Lothar Myer in Germany and Mendeleeff in Russia, about 1869, to arrange and make respectable the periodic system of the elements which is now used as the working basis of modern chemical philosophy.[5] Gaps were found to exist, however, and Mendeleeff was able to predict and describe in advance of their discovery the appearance and the properties of a number of these unknown elements and their compounds. Science later on had the satisfaction of seeing these predictions verified. To the layman this seems a wonderful performance, more marvelous even than the prediction of the existence of the planet Neptune by its action upon Uranus long before its actual discovery. As a matter of fact, granting that the theory of the periodicity of the elements really expressed a great natural law, Mendeleeff's bold predictions were a hardly more astonishing accomplishment than

[5] See Mendeleef's *Periodic Classification of the Chemical Elements*, p. 29.

MENDELEEF'S PERIODIC CLASSIFICATION OF THE ELEMENTS

Series.	Zero group.	Group I.	Group II.	Group III.	Group IV.	Group V.	Group VI.	Group VII.	Group VIII.		
0	*x*	—	—	—	—	—	—	—	—	—	—
1	*y*	Hydrogen, H = 1·008	—	—	—	—	—	—	—	—	—
2	Helium, He = 4·0	Lithium, Li = 7·03	Beryllium, Be = 1·1	Boron, B = 11·0	Carbon, C = 12·0	Nitrogen, N = 14·04	Oxygen, O = 16·0	Fluorine, F = 19·0	—	—	—
3	Neon, Ne = 19·9	Sodium, Na = 23·05	Magnesium, Mg = 24·1	Aluminium, Al = 27·0	Silicon, Si = 28·4	Phosphorus P = 31·0	Sulphur S = 32·06	Chlorine Cl = 35·45	—	—	—
4	Argon, Ar = 38	Potassium, K = 39·1	Calcium, Ca = 40·1	Scandium, Sc = 44·1	Titanium, Ti = 48·1	Vanadium, V = 51·4	Chromium, Cr = 52·1	Manganese, Mn = 55·0	Iron, Fe = 55·9	Cobalt, Co = 59	Nickel, Ni = 59 (Cu)
5	—	Copper, Cu = 63·6	Zinc, Zn = 65·4	Gallium, Ga = 70·0	Germanium, Ge = 72·3	Arsenic, As = 75·0	Selenium, Se = 79·0	Bromine, Br = 79·95	—	—	—
6	Krypton, Kr = 81·1	Rubidium, Rb = 85·4	Strontium, Sr = 87·6	Yttrium, Y = 89·0	Zirconium, Zr = 90·6	Niobium, Nb = 94·0	Molybdenum, Mo = 96·0	—	Ruthenium, Ru = 101·7	Rhodium, Rh = 103·0	Palladium, Pd = 106·5 (Ag)
7	—	Silver, Ag = 107·9	Cadmium, Cd = 112·4	Indium, In = 114·0	Tin, Sn = 119·0	Antimony, Sb = 120·0	Tellurium, Te = 127	Iodine, I = 127	—	—	—
8	Xenon, Xe = 128	Cæsium, Cs = 132·9	Barium, Ba = 137·4	Lanthanum, La = 139	Cerium, Ce = 140	—	—	—	—	—	—
9	—	—	—	—	—	—	—	—	—	—	—
10	—	—	—	Ytterbium, Yb = 173	—	Tantalum, Ta = 183·0	Tungsten, W = 184	—	Osmium, Os = 191	Iridium, Ir = 193	Platinum, Pt = 194·9 (Au)
11	—	Gold, Au = 197·2	Mercury, Hg = 200·0	Thallium, Tl = 204·1	Lead, Pb = 206·9	Bismuth, Bi = 208	—	—	—	—	—
12	—	—	Radium, Rd = 224	—	Thorium, Th = 232	—	Uranium, U = 239	—	—	—	—

an expert musician calling off the musical notes of which any given chord is composed, although he does not see the notes struck. If any component note is left out, the musician should not only be able to detect its absence but also to describe its harmonic quality.

In 1815, William Prout (1785-1850), an English physician and chemist, had published anonymously a paper on the relation between the specific gravities of bodies in their gaseous state and the weights of their atoms. In this paper, Prout calculated that the atomic weights of a number of the elements were exact multiples of that of hydrogen, and he suggested that the protyle of the ancient Greek philosophers is realized in hydrogen from which all other elements are formed by condensation or grouping. Prout's hypothesis has not been substantiated by careful quantitative investigation of the atomic weights, but the general idea of the gradual evolution of the elements from some primordial mother element continues to occupy the minds of the more speculative among modern thinkers. Sir William Crookes returned to this theory about 1883 as the result of certain irreconcilable quantitative results he had obtained while investigating some of the rarer elements and which led him to the provisional conclusion that the so-called elements are in reality compound molecules produced by a cyclic evolution from an original stuff or "protyle." Whatever the future may have in store for us in information as to the origin of matter, we may, however, feel confident that elementary atoms as we know them are to all practical intents and purposes eternal and unchangeable, veritable constants of nature, the building blocks of the universe.

In closing this chapter, some reference should be made to the fact that many of the marvellous phenomena of chemistry, physics and astronomy are now explained by a

new concept of the Daltonian atom. We have seen that all matter is made up of molecules and atoms constantly in motion, obeying orbital laws of affinity just as controlling and compelling on their plane of magnitude as the movements of the heavenly bodies in the Cosmos. The work of J. J. Thomsen, the eminent English physicist, has now led to the belief that the invisible atoms of elementary matter are themselves composed or made up of a great number of electrons or corpuscles of a mass of about one one-thousandth of that of the hydrogen atom. This view presents the Prout's hypothesis and the speculation of Crookes and others in a new light, and explains many of the marvellous phenomena of the old as well as the new chemistry. The electrons are conceived as points of negative electric energy in inconceivably rapid motion, held by affinity in and about an electro-positive nucleus just as water is absorbed in a sponge.[6]

In considering the constitution of the whole visible universe, we can perceive nothing else than motion and affinity, and back of and controlling these a great inscrutable initiative impulse. The suns, planets and satellites revolve about each other with orbital precision and regularity, guided and constrained by the unknown affinity we call gravity; from these motions man receives the concept of time and so measures it. The heavenly bodies in turn are made up of molecules and these of atoms, and these again of electrons, all guided and controlled by the laws of affinities as yet unknown. Under these concepts, matter is nothing more nor less than energy made manifest.

[6] Since the author's manuscript was prepared the work of Irving Langmuir has shed new light on the configuration of the elections in the atomic systems and brings out very strongly the analogy between the arrangement of the solar and the atomic structures.

Geoffrey Martin has eloquently referred to some of these aspects of chemistry. Let us hear him:

Suppose we place an oxygen atom at a small distance from a pair of hydrogen atoms and let us imagine that the atoms are in a fit condition for reacting chemically. These atoms exert mighty chemical forces on each other and instantly begin to rush together. The closer they get the more powerful become the attractive forces and the swifter the atoms fly until they meet with an immense velocity, usually not directly colliding but grazing each other like comets grazing the sun. The final velocities with which the hydrogen atoms meet the oxygen atoms are often over four miles a second. The atoms then commence to revolve one round the other and thus a molecule of water is born. Of course the impulse of the rush carries the atoms far beyond their mean position of equilibrium, and consequently violent surgings backwards and forwards—like the swingings of a pendulum —occur in the tiny new-born molecular system. Since millions upon millions of atoms of oxygen thus unite simultaneously in this way with twice their number of hydrogen atoms, it is obvious that the previously slow-moving mixture of molecules suddenly becomes converted into a mass of swiftly moving molecules. . . . The whole reaction has taken only the fraction of a second to complete itself. Short as this time is to us, yet it represents to an atom an eternity of time within which vast multitudes of atomic events are capable of occurring, of slowly growing into prominence, and then gradually dying out again. For example, we can calculate from the kinetic theory of gases that within a single second an atom of hydrogen would have ample time to revolve three million million times about an atom of oxygen in the water molecule. Calling familiarly the time of revolution an "atomic year" we see that a single second of our time is worth three billion of atomic years. So that if the above reaction between hydrogen and oxygen gases took only the one-thousandth part of a second to complete itself, nevertheless this time represents a vast interval of 3000 million atomic years! If we, for the sake of illustra-

tion, imagined that the water molecules were inhabited and that the time it took an atom of hydrogen to revolve around an atom of oxygen in this molecule bore to these inhabitants the same relationship that the time the earth takes to travel around the sun bears to us, the atomic inhabitants would be quite unaware of the molecular catastrophe proceeding so swiftly about them. The stellar heavens above us may, for all we know, be the theatre of a similar swift change which may complete itself in a few billion years. Yet so vast is this period of time that the changes now proceeding seem immeasurably slow to us. In the eyes of a being, however, to whom a billion years seem but a second, or in whom a sense of time is non-existent, the whole mighty universe might appear to be in the throes of a swift catastrophe which completes itself instantly. Man, with his empires and cities, would, to such a being, seem but a momentary excrescence, appearing suddenly in the never-ending abyss of time and then vanishing forever. . . . With such facts facing us on every side it is madness to assert that the progress of Science means the destruction of the spirit of reverence and of wonder. To such criticisms Science may proudly reply in the words of the Earth-Spirit of Goethe's *Faust:*

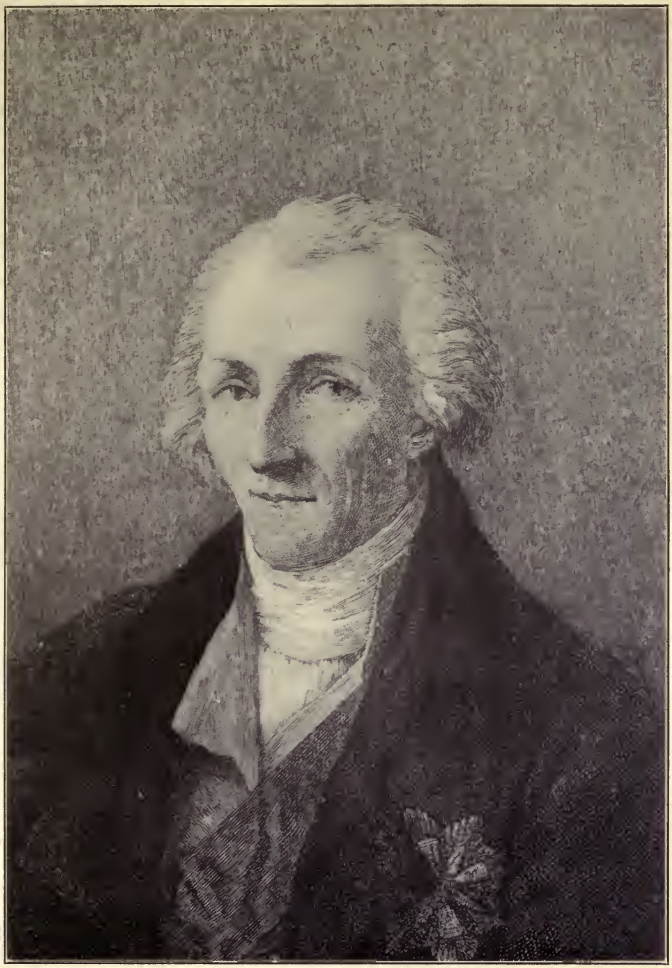
> "At the whirring loom of Time unawed,
> I weave the living garment of the Lord."

We have now reviewed some few of the more salient and interesting points connected with the history of chemistry in the past and have brought our subject up to that period in which chemistry really takes its place in the service of man. In the next chapter we shall, however, have to retrace our steps and introduce some further early history that bears, though indirectly, in a most interesting manner on the development of our subject.

CHAPTER II

CHEMISTRY IN THE SERVICE OF MAN

THE opening of the nineteenth century witnessed the dawn of what is properly spoken of as modern civilization. In a welter of bloodshed and fratricidal strife, the great revolutions of America and France had laid down the foundations of the right of the individual to life, liberty and the pursuit of happiness. The history of that extraordinary epoch rings with the military achievements and constructive statesmanship of Washington and Bonaparte, but behind the scenes the stage was being set for a scientific revolution, the results of which were to affect the personal lives and methods of living of the generations, then as well as even yet, unborn. If the question were asked, on what one influence more than another the conditions of modern human life depend, the answer would immediately be forthcoming in one word—Energy. This is perhaps best exemplified by the rapid growth in recent years of the production of coal. With a population of a hundred million in the United States alone, we are at present producing and using up each year approximately 600,000,000 tons of coal, and even this is not enough. The development of enormous water powers for special uses in peace and war is being strenuously urged and the problem is receiving the closest attention of the engineering professions and should receive that of the state and national governments.



BENJAMIN THOMPSON, COUNT RUMFORD

I shall make it part of my present task to invite attention to a brief review of the beginning and development of this modern strenuous age, insofar as science has most particularly affected it. It is an entertaining story and one in which we should be particularly interested, inasmuch as the beginning of this epoch was affected by an event that took place in colonial America.

On March 26, 1753, there was born on a farm at Woburn, in the vicinity of Boston, a poor boy who was destined in later years and after a most adventurous and exciting life to be the means of starting the modern application of science to the problems of industry and energy. This boy, who bore the rather unromantic name of Benjamin Thompson, got as much schooling and no more than was current among New England farm lads prior to the Revolution, but, as history shows, genius needs but little schooling. We are told that at fourteen, Thompson was sufficiently advanced in mathematics to calculate a solar eclipse within four seconds of accuracy, and we may well ask ourselves how many school or college graduates of the present day could match this accomplishment. From the romantic story of Thompson's life, we learn that he was apprenticed as a shop boy in Salem at the early age of thirteen, and became a store clerk in Boston at seventeen. Popular with the ladies all his life long, he married at nineteen, or, as he put it himself, he was married by a rich and well connected widow of thirty-five whose home was at the little village of Rumford, N. H., now called Concord. Though not a happy one in the conventional sense, this marriage was the foundation of Thompson's success and profoundly affected the development of civilization under modern conditions, as we shall presently see. Moving with his wife to Rumford, he became acquainted with the Royal Governor Wentworth of New Hampshire,

who soon succeeded in making a thorough going Tory of his fascinating young friend. A daughter was born of this marriage, but soon after, deserting wife and child, he was obliged to flee from the wrath of his patriot neighbors and take refuge on a British ship. Armed with despatches and letters of introduction from Governor Wentworth, Thompson made his way to London where with his usual facility he soon ingratiated himself with Lord George Germain, Secretary of State, who gave him an under-secretaryship and followed this up with promotion after promotion.

In the meantime, scientific studies, with such resources as London could at that time offer, consumed all the young man's leisure hours. Scientific monographs on such timely subjects as the explosive force of gunpowder, the construction of firearms, and a system of signalling at sea caught the attention of the nation, and in 1779, at the early age of twenty-six, he was elected a fellow of the Royal Society which was then, as now, one of the greatest of scientific honors. Time will not permit us to follow the extraordinary adventures and triumphs of this man's life from this period on. With a few more brief words, we must hurry over to the crowning achievement of his career.

In 1783 he crossed to the continent, a fellow passenger happening to be Gibbon, the historian, who in writing home to his friend Lord Sheffield, of this chance meeting, speaks perhaps somewhat ironically of his travelling acquaintance as Secretary-Colonel-Admiral-Philosopher Thompson. Reaching Bavaria, our adventurer presented letters to the Elector Maximilian who, in turn falling a victim to Thompson's fascination, heaped offices, honors and authority upon him. During the eleven years he resided at Munich, he occupied the positions of Minister of War, Minister of Police, and Grand Chamberlain. His scientific studies and

publications were prolific and marvellous, and he was the first to understand and elucidate the laws of heat. He put a stop to the brigandage and organized beggary that was a continual menace to the Bavarian population. Under his orders, twenty-six hundred mendicants and bandits were arrested on one day alone, placed in an institution where they were fed, housed and clothed, and put to profitable labor. Thompson issued a public statement in which he said: "To make vicious and abandoned people happy, it has generally been supposed necessary to first make them virtuous. But why not reverse this order? Why not first make them happy and then virtuous?"

All this time, and by means perhaps of applying this philosophy to his own case, Thompson was amassing a large personal fortune. In 1791 he was made a count of the Holy Roman Empire, and chose the title Count Rumford from the name of the little New Hampshire village where the deserted wife and daughter still lived.

After many more adventures, Rumford in 1799 returned to London to found and endow a group of research laboratories and lectureships under the name of the Royal Institution of Great Britain. This research foundation, the first specific organization of its kind, marked an epoch in the effect of science on civilization, as we shall soon see.

About that time a young man named Humphry Davy was earning a somewhat precarious living as a more or less itinerant lecturer and investigator of such topics in chemistry and physics as were current in those days. In 1799 he had accidentally discovered nitrous oxide (laughing gas) and proved its anæsthetic and intoxicating effects when inhaled. This discovery caught the popular imagination, and in a day Humphry Davy was famous. The gas was inhaled by Southey and Coleridge among other distinguished persons,

while fashionable London society made it a ten days' wonder. Rumford promptly chose the recently knighted Humphry Davy to be scientific lecturer and director of his new research institution, and there began a series of events, with the development of which our progress, even our very lives, are to this day intimately connected.

It should not be forgotten that in those days there were many scientific facts and generalizations on the very brink of discovery. Undiscovered laws of nature were almost beckoning to man to uncover them. As an analogy of what is meant, the discovery of gold in California may be cited. The early pioneers found their nuggets near the surface and more or less easy to collect, but as time went on it became more and more difficult to unearth the gold, so that it became necessary for men to organize into companies and to operate on a larger scale in order to achieve their purpose with success. Humphry Davy and his co-workers once furnished by the genius and liberality of Count Rumford with the facilities and tools of scientific research, began a series of brilliant discoveries which has profoundly affected and changed the current of human development and destiny. Before we can follow these discoveries, it will be necessary to go back a little and inquire into the status of scientific knowledge just previous to the foundation of the Royal Institution.

It is interesting in passing from the career of Count Rumford to refer to the fact that before his death he showed his feeling for the land of his birth by establishing the Rumford medal of the American Academy of Arts and Sciences and by endowing the Rumford professorship in Harvard University. Rumford recived appropriate punishment for his desertion of his American wife, for in his later years he married in Paris the widow of the great Lavoisier. With this

strenuous lady he led a stormy life and on one occasion we read that she threw him downstairs to his great injury. Rumford died suddenly on August 21, 1814, in the sixty-second year of his age, having accomplished a much greater contribution to chemistry in the service of man than has ever been very generally realized.

We have already noted in a previous chapter the work of the great phologistonists of the eighteenth century. We have discussed the contributions of Priestley in England and Scheele in Sweden, the co-discoverers of oxygen gas which remained for Lavoisier to recognize and describe a few years later. But all this time there was working in and about London an unobtrusive, somewhat shabby and very eccentric nobleman whose labors and accomplishments form a direct connecting link between the first beginnings of chemistry and some of the great industrial accomplishments of the twentieth century, which so profoundly affect the present and the future destiny of humanity. Lord Henry Cavendish, of the famous line of the Dukes of Devonshire, was born in 1731 and grew up to be reputed one of the richest men in England or of his time. This extraordinary personage did not in the remotest degree resemble in his tastes and habits the other rich gentlemen of his day, although Robert Boyle of the line of the Earls of Cork had already set a distinguished example for future scions of the nobility to emulate. Cavendish held little intercourse with his fellows, and we are told that his chief object in life seems to have been to avoid social attention. After his publications in the proceedings of the Royal Society had already made him famous, a French savant crossed the Channel to attend a soiree of the Royal Society, with the express purpose of meeting Cavendish and conversing with him on scientific subjects. It is related that the French visitor

arrived at the rooms rather late, and as he mounted the long staircase he perceived a tall, ungainly, rather shabby gentleman preceding him. The guest proffered a polite request that the great Lord Cavendish be pointed out to him immediately on his arrival at the rooms. He was somewhat astonished when his ungainly companion on the staircase, without a word, turned around and beat a hasty retreat homeward. It was Cavendish himself, whose intense and awkward shyness was not proof against the eloquent compliments of the visiting Frenchman. We read that Cavendish was tall and thin, his dress old-fashioned, he had an impediment in his speech, and his air of timidity and reserve was almost ludicrous. His dinner was ordered daily by a note placed on the hall table and his women servants were instructed to keep out of his sight on pain of dismissal. Naturally Cavendish never married, he died unattended and alone, in 1810, preferring not to call for assistance from his servants even when he felt himself expiring. He left to his legal heir over one million pounds sterling, an enormous fortune for that day. We are told that Cavendish held portrait painters in abhorrence and steadfastly refused to sit for his portrait. The only picture extant was produced from a drawing by Alexander from furtive sketches made while waylaying the philosopher in the streets.[1]

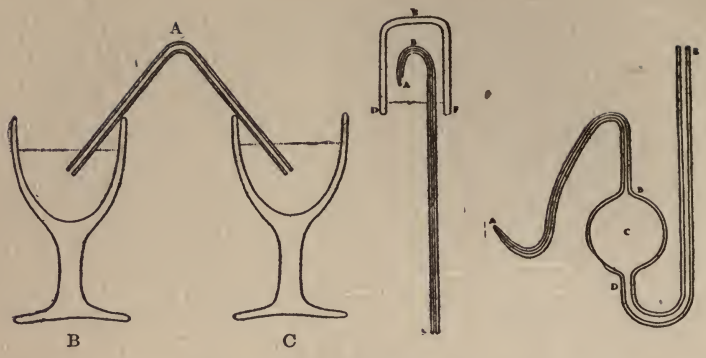
So much for the character of this uncouth philosopher whose personality and career formed so strange a contrast to his brilliant contemporary Count Rumford. Yet the work and contributions of these two men were destined to exert together a profound influence on the direction and development of chemistry applied to the service of mankind. We may now turn our attention to the significant researches which have put humanity under a debt to Henry Cavendish

[1] Frontispiece.

for all time. Although a phlogistonist to the end of his life, Cavendish was not limited or bound by scientific prejudice to the same degree as was Priestley; his scientific work which was voluminous and original is distinguished for the wideness of its range and for its extraordinary exactness and accuracy. To Cavendish nitrogen gas was phlogisticated while oxygen was dephlogisticated air. Hydrogen he looked upon as phlogiston itself. In this, he was, of course, in error and it is the more extraordinary that in spite of this handicap of ignorance he should have made the great deductions and discoveries that he did.

Starting from an experiment described by Priestley in which a certain John Waltire fired a mixture of common air and hydrogen (inflammable air) by means of an electric spark (which we may interpolate is analogous to what we do today in an internal combustion engine), Cavendish arranged an ingenious piece of apparatus into which he could introduce any quantitative mixtures of gases which he desired, and pass through them a succession of electric sparks from a static machine. The sparking tube was closed or sealed at the bottom by immersion in a liquid which was sometimes mercury or again any watery solution that might be selected. In fact, Cavendish's first apparatus was so simple in relation to the great discoveries that were made with it that it seems worthy of description. The apparatus consisted of a glass tube bent into the form of an acute angle or elbow, and two wine glasses. The arrangement was as follows:

The tube A having been filled with the same liquid as that contained in the glasses B and C, air or any desired mixture of gases could be introduced by displacement into A by means of a little hook ended delivery tube. The wire terminals from the static machine could then be pushed up the



Cavendish's Simple Apparatus in Which the First Nitrogen Fixation Experiment Was Made

open tube ends in B and C and brought as near together as desired. If any condensation of the atmospheres in A took place during the passage of the electric sparks, the liquid in the glasses would rise in the arms of the tube and thus furnish a quantitative measure of the amount of the condensation. With this apparatus Cavendish proved that water was composed of two volumes of hydrogen (inflammable air or phlogiston) united with one volume of oxygen (dephlogisticated air). This seems simple now but it was marvellous in those days to learn that common, familiar water was composed of two invisible airs or gases, combined in a definite relation by weight and by volume. When Cavendish let up a mixture of common air and hydrogen into his tube, he found that invariably nitrous air (nitric oxide gas) was formed. He put what he called "soap lees" into his wine glasses, and noted the formation of nitre. "Soap lees" was the alkaline solution made by leeching hardwood ashes with water and we now know it was mainly a solution

of potash. The next step was to introduce common air into the sparking tube, mixed with an excess of oxygen (dephlogisticated air). When no more condensation took place, the soap lees were examined and found to contain a definite quantity of nitre (potassium nitrate). This was the first recorded observation of the fixation of atmospheric nitrogen, a discovery that was the germ of the solution of the food problem for generations of men, perhaps even of civilizations, as yet unborn. It was a discovery too that held within it the germ of the great world war which was to come something over a century and a quarter later. The Germans could not have undertaken a world war if modern chemical engineering had not developed methods of oxidizing or fixing atmospheric nitrogen on a great scale of operation. But all this was obscure in Cavendish's day and was to remain more or less dormant like a seed in cold earth for a long time to come.

We have time only to refer to one more of the careful observations of Cavendish which was to lie obscurely hidden and unnoted for one hundred years, and which resulted finally not only in an extraordinary application to modern industry but which also set up a train of chemical and physical discovery of a very wonderful nature, the end of which is not yet in sight. In 1887 John William Strutt (Lord Rayleigh) accepted the post of professor of natural philosophy at the Royal Institution of Great Britain, which institution was founded, as we have learned, in the year 1800 by Benjamin Thompson (Count Rumford). For some years previously, Lord Rayleigh had been redetermining the vapor density and molecular weight of nitrogen by weighing the gas in large glass globes, using the utmost refinements of modern science to insure the most minute accuracy. Some curious inconsistencies in these weights were encountered.

Whenever the nitrogen was prepared by removing oxygen and all known impurities from air, it invariably weighed a little more than pure nitrogen which had been prepared by heating ammonium nitrite. For a long time Lord Rayleigh suspected that these discrepancies were due to his own faulty workmanship and he has recorded that at one time he became so disgusted with himself that he was on the eve of abandoning the research. At this juncture, however, he personally related his difficulties to his friend and colleague, Professor (now Sir) James Dewar, Fullerian Professor of Chemistry at the Royal Institution. The present writer visited the Royal Institution some time in the early nineties, with a letter of introduction to Sir James Dewar from his friend, Prof. Josiah Cook, of Harvard University. This was at the very time these interesting discussions were going on. According to the writer's recollection, Lord Rayleigh had raised the point as to what evidence really existed that the air after removal of all known impurities consisted of nothing more than oxygen and nitrogen. He pointed out that if it could be assumed that the air normally contained some small quantity of an unknown inert gas heavier than nitrogen, his anomalous weights could be accounted for. To the best of the writer's recollection, Professor Dewar suggested that though such an assumption was improbable it was by no means impossible, since if such an unknown gas existed it must be singularly inert to have escaped the many searching investigations which had been made on the constitution of the atmosphere. It was then proposed to refer back to Cavendish's original memoirs, which described his experiments on the composition of air.

If these eminent scientists had been discussing such a subject somewhere in America, it is probable that they would have had to go a journey before they could have consulted

Cavendish's original papers. In this case, however, thanks to the liberality of the American Benjamin Thompson, it was but a step to the next room where not only Cavendish's publications but the very apparatus which he had used were preserved. In his memoirs of 1795, nearly a century previously, Cavendish had written:

As far as the experiments hitherto published extend, we scarcely know more of the phlogisticated part of our atmosphere than that it is not diminished by lime-water, caustic alkalies, or nitrous air; that it is unfit to support fire or maintain life in animals; and that its specific gravity is not much less than that of common air; so that, though the nitrous acid, by being united to phlogiston, is converted into air possessed of these properties, and consequently, though it was reasonable to suppose, that part at least of the phlogisticated air of the atmosphere consists of this acid united to phlogiston, yet it may fairly be doubted whether the whole is of this kind, or whether there are not in reality many different substances confounded together by us under the name of phlogisticated air. I therefore made an experiment to determine whether the whole of a given portion of the phlogisticated air of the atmosphere could be reduced to nitrous acid, or whether there was not a part of a different nature to the rest which would refuse to undergo that change. The foregoing experiments indeed, in some measure, decided this point, as much the greatest part of air let up into the tube lost its elasticity; yet, as some remained unabsorbed, it did not appear for certain whether that was of the same nature as the rest or not. For this purpose I diminished a similar mixture of dephlogisticated (oxygen) and common air, in the same manner as before (by sparks over alkali), till it was reduced to a small part of its original bulk. I then, in order to decompound as much as I could of the phlogisticated air (nitrogen) which remained in the tube, added some dephlogisticated air to it and continued the spark until no further diminution took place. Having by these means condensed as much as

I could of the phlogisticated air, I let up some solution of liver of sulphur to absorb the dephlogisticated air; after which only a small bubble of air remained unabsorbed, which certainly was not more than 1/120 of the bulk of the dephlogisticated air let up into the tube; so that, if there be any part of the dephlogisticated air of our atmosphere which differs from the rest, and cannot be reduced to nitrous acid, we may safely conclude that it is not more than 1/120 part of the whole.

After this discovery, Lord Rayleigh immediately realized that though Cavendish had not definitely proved the existence of an unknown constituent, it was highly probable that his residue was really of a different kind from the main bulk of the "phlogisticated air." Sir William Ramsay, professor of chemistry in University College, London, an eminent and ingenious experimentalist, was invited to review and repeat Cavendish's work, with the result that in 1894 Rayleigh and Ramsay were able to announce to the British Association the discovery of a new gas in the atmosphere, which they named argon from the Greek word meaning "inert." This gas is present, as Cavendish suggested, in an amount approximating one per cent.

The isolation of argon opened up a new field of investigation in modern chemistry, which we will have occasion to refer to again in another chapter. Argon has recently found an industrial application as the filling atmosphere in incandescent electric light bulbs.[2]

We must now return to the year 1800 and the foundation of the Royal Institution, for this foundation more than any other event in history signalized the entrance of chemistry

[2] A letter from Dr. W. R. Whitney of the General Electric Co. states that practically all the ordinary incandescent lamps now made, between 50 and 1000 Watts, contain argon (about 80 per cent, 20 per cent being nitrogen). Also the 15 and 20 ampere street series lamps contain argon. The argon is obtained from fractionation of liquid air.

into the service of man. The first task imposed on Sir Humphry Davy (1778-1829), the newly selected manager, was the delivery of a course of lectures on the chemical principles of tanning. Next followed practical courses on the application of chemistry to agriculture, but it was in his studies and research in electro-chemistry that Davy achieved his greatest fame. The terrible explosions which were continually taking place in coal mines had long been a handicap to the development of civilization. In 1815 Davy began a laboratory investigation of "fire damp" gas sent from the mines at New Castle. These studies led to the discovery of the famous Davy safety lamp. A large collection of the different models made in the course of these inquiries is still in the possession of the Royal Institution.

Space will not permit of reference to the enormous number of contributions to theoretical and applied chemistry which issued from the Royal Institution during Humphry Davy's incumbency. In spite of Davy's brilliance and accomplishments, he never has been looked upon as a scientific star of the very first magnitude. One of these surpassingly bright stars was soon to rise above the horizon. About the year 1800 there was (as Tyndall has related the story) running about the London pavements a bright-eyed errand boy with a load of brown curls upon his head and a packet of newspapers under his arm. The son of a humble blacksmith, this street lad was glad to earn a few pennies by minding the great Humphry Davy's horse as he drew up at the door of the Royal Institution in Albemarle Street. But more than this, the lad would creep into the dark gallery of the lecture hall and try to write down so much of the great man's lectures as he could understand. Shortly afterward, apprenticed to a journeyman bookbinder, he used each leisure moment and burned the midnight oil in his ef-

fort to attain his heart's desire, which was to follow in the footsteps of his hero and patron, Humphry Davy. And Davy had kept his eye on this bright lad, and on March 1, 1813, engaged him as a laboratory assistant in the Royal Institution. As the direct result of the birth of a poor boy on a farm at Woburn, Mass., just sixty years later a poor boy from the London pavements was given his opportunity, and the work of Michael Faraday at once began to lay the foundations of modern electro-chemistry and electrical engineering.

Let us see if this statement is in any way an exaggeration of the truth. But first let us linger one moment for one more personal glimpse into the connection formed between Michael Faraday and Humphry Davy. In October, 1813, Sir Humphry and Lady Davy travelled to the continent, as Sir Humphry was to be the recipient of foreign honors and orders to be received from the hands of royalties at the instigation of the various academies of science and philosophy. On this famous occasion, Faraday, upon the insistence it would seem rather of Lady Davy than of Sir Humphry travelled as a valet and joined the servants at their meals. Tyndall has related that Davy was considerate, but Lady Davy was the reverse. She treated him as an underling. They halted at Geneva. De la Rive, the elder, had translated Davy's published researches for the benefit of French academicians. He welcomed the party to his country residence. Both scientists were sportsmen and went shooting together. Faraday charged Davy's gun, while De la Rive charged his own. The Genevese philosopher was struck by the intelligence of the young man and entered into conversation with him. It seemed impossible that a person with such charm of manner could be a mere servant. On inquiry, De la Rive was shocked to learn that the soi-disant

MICHAEL FARADAY WASHING APPARATUS FOR SIR HUMPHREY DAVY

domestic was really a laboratory assistant; and he immediately proposed that Faraday should join the masters instead of the servants at their meals. To this, Davy, out of weak deference to his wife, objected; but an arrangement was made that Faraday thereafter was to have his food served in his own bedroom. It is a curious and interesting fact that on Faraday's subsequent visit to the continent years later, he was fêted and dined, seated at the right hand of princes and rulers, while amongst his intimate friends and regular correspondents we find the names of Humboldt, Herschel, Dumas, Liebig, Becquerel, Oersted, Phlücker, Du-Bois-Reymond, Louis Napoleon, and many others.

But to return to the laboratory of the Royal Institution and the work which was to come forth from it. In 1820 Oersted of Copenhagen made the wonderful announcement that magnetism and electricity were correlated forces and immediately the acute mind of Dr. Wollaston in England perceived that if Oersted's observations were correct, a wire carrying a current ought to rotate around its own axis under the influence of a magnetic pole. In April, 1821, Wollaston came to the laboratory of the Royal Institution and devised an experiment which failed. Faraday, who had for some time past been experimenting with the problems of electro-chemistry, now took up the study of electro-magnetism, and the brilliant series of discoveries which were to produce so extraordinary an effect upon the human race almost immediately began. In the autumn of the same year that Wollaston's experiment failed, Faraday succeeded in causing a wire carrying an electric current to rotate around a magnetic pole. This was not Wollaston's idea, but it was closely related to it, and demonstrated the fundamental principle on which the action of the electric dynamo generator and the electric motor depend. For the next ten years

scientific miracle after miracle issued from the research laboratories which the genius of Benjamin Thompson had founded and the genius of Michael Faraday illumined. By 1831 Faraday had not only generated currents by magnets and made magnets both permanent and transitory by currents, but he generated currents by currents, thus establishing the principles of induction. Faraday's law established for all time the great principle of electro-chemical decomposition and gave birth to a new line of human activity. The results of these original researches in electro-magnetism passing into the hands of many men, developed in about a half a century the following tools of human energy: The electric dynamo and motor, the electric light, the electric telegraph and the telephone both by wire and wireless, the electric propulsion of street cars and railways. Through the development of the electro-magnetic ignition system, the gasoline and other internal combustion engines, and the automobile, the aeroplane, and the submarine quickly followed. But above and beyond all in its ultimate promise to the human race comes the possibility of deriving energy and power from natural sources which will exist long after natural resources have been exhausted. Even after the coal has all been burned and the world's nitrate beds exhausted, it is presumable that water still will be running down the watersheds of the world, harnessed to the whirring wheels doing the world's work under the influence and control of the electro-magnetic principles, in the development of which Benjamin Thompson and Michael Faraday were perhaps the humble instruments of over-shadowing design guiding the destinies of mankind. And who shall say that these same electro-magnetic principles will not some day be linked to some source of natural energy more etherial than moving

water, and thus make wonders real of which at present we only dream?

As we pass to the consideration of other phases of our subject, it is interesting to note that just as the first British research institution was founded by an American, the first American purely research institution was founded in Washington by an Englishman, John Smithson of London, to promote science and the useful arts. Although not as prolific in discovery as the Royal Institution, it must not be forgotten that under this foundation Joseph Henry labored for many years to the extension and development of contemporary science in America. It was here that the patient, though to him unrewarded, labors of Samuel P. Langley worked out the principles which permitted other men to develop the successful heavier-than-air flying machine and so in a few years make true Tennyson's wonderful prophesy:

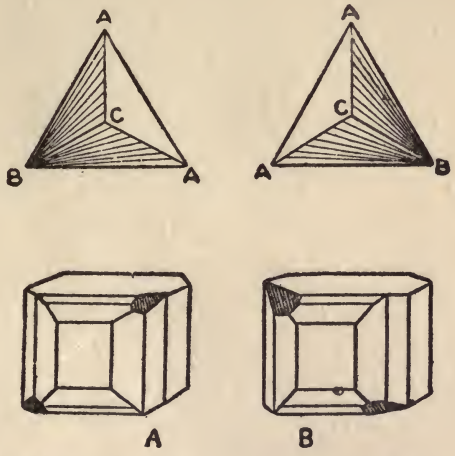
> Heard the Heavens filled with shouting,
> And there rained a ghastly dew
> From the nation's airy navies
> Grappling in the central blue.

While we have been following the great contributions to chemistry which took place in England during the early part of the nineteenth century, chemists on the continent had not been idle. Volta (1745-1827), the Italian physicist, made contributions to the knowledge of electricity, which made much of the work of Cavendish, Davy and Faraday possible. Berzelius (1779-1848) in Sweden, following up Volta's discoveries, greatly extended knowledge in the field of electro-chemistry, as indeed he did in every other field of chemistry. In Germany Justus von Liebig (1803-1873) founded a new school of chemistry at Giessen, which became the mecca of all the distinguished students of chemistry of

the day. Liebig first seriously applied the study and principles of chemistry to the problems of agriculture and food, and prepared the way for the great contributions of the Frenchman, Pasteur, which were soon to follow. One of the greatest of contributions of all time to chemistry and science in general was the elaboration by Bunsen and Kirchhoff of spectrum analysis which has put a new weapon of great range into the hands of chemists and astronomers. By means of a comparatively simple apparatus, elementary bodies are enabled to signalize their presence and to all intents and purposes write their own autographs. With this instrument the chemical composition of distant suns can be analyzed with as much exactness as though we had the material in our laboratories, while numbers of unknown elements on the earth, as well as in the atmosphere of the sun have been discovered and made useful for man's purposes.

We come now to the crowning contribution of pure chemistry to the development of science in the nineteenth century. We have referred in a previous paragraph to Michael Faraday as a scientific star of the first magnitude, but another was destined to appear before the century drew to a close. Perhaps one of the most remarkable discoveries of modern chemistry is the existence of bodies of identical composition but quite different properties. This is called isomerism, and two or more such bodies are known as isomers. The great Berzelius had noted that two separate tartaric acids of identical composition could be recovered from the dregs or lees of wine, and it had been noted that when a ray of polarized light was passed through a water solution of these two acids, one possessed the power of turning the plane of the polarized ray to the right while the other possessed no rotary power and was to all intents ap-

parently optically inactive. In reality, acid B was just twice as optically active as acid A. It remained for the genius of a young Frenchman, Louis Pasteur (1822-1895), to illumine this unexplainable observation and to begin a series of researches, the results of which will profoundly affect the destiny of the human race for all time to come. Pasteur showed that the inactivity of the one acid was due to the fact that it was composed of two isomeric, optically active constituents, one the ordinary dextro-rotary acid and the other a new acid which possessed an equally power-



Crystals which when dissolved in water turn the plane of polarization to the right.

Crystals which when dissolved in water turn the plane of polarization to the left.

ful left-handed power. He then went further and explained how the arrangement of the atoms in the configuration of the two molecules was similar to that of a tetrahædral body and its mirror image. While experimenting with these isomeric bodies from wine lees, Pasteur was led to the com-

mencement of his classical researches on fermentation. The ordinary green mould (penicillium glaucum) that appears and grows on damp organic matter is familiar to every one. Pasteur made the curious discovery that when this mould grew in solutions containing the optically inactive acid, the right-handed acid was destroyed, the left-handed variety remaining unchanged. Here was an observation to excite the attention of science for what possible influence could these lowly living cells be exerting in order to carry out such a selective chemical action? Before Pasteur's time, the phenomenon of fermentation was considered strange and obscure. Attacking a new and untried field of investigation, assailed by skepticism, prejudice and even ridicule on almost every hand, the incomparable genius of this young Frenchman never faltered until he had revolutionized the science of chemistry and medicine and practically founded as new branches of science fermentology, biology, and pathology.

Michael Faraday throughout his career was occupied only with the purely scientific aspects of his subjects and could not be induced to betray the slightest interest in the application of new principles to the service of mankind; this he was quite willing to leave to others. But not so Pasteur, who wrote: "There is no greater charm for the investigator than to make new discoveries; but his pleasure is heightened when he sees that they have a direct application to practical life." Thomas Huxley has stated that the practical money value of Pasteur's discoveries to his native land was sufficient to cover the entire war indemnity paid by France to Germany in 1870. He studied and cured the silkworm disease which threatened one of his country's greatest industries. He successfully applied the same principles to the cure of a disease which was attacking the vineyards in the

wine growing districts. He developed the principles of sterilization and pasteurization of wounds and foods, thereby saving the lives of countless millions of human beings. Finally he attacked that most hideous of diseases, rabies, and showed how it could be controlled and cured. Pasteur, although a most simple, affectionate and kindly-natured man, did not hesitate to prosecute his studies by means of animal experimentation. He would not have been popular today, with numbers of well meaning but misinformed ladies and gentlemen who assail the lobbies of legislative halls in the effort to effect prohibition of all forms of animal experimentation, carried out for the purpose of acquiring knowledge in order to alleviate human suffering and disease. With curious inconsistency, these advocates pack the legislative corridors, warmed and adorned with the skins of animals that have been cruelly trapped and left to starve to death in their frigid habitats.

We have not space to follow further Pasteur's wonderful contributions to knowledge, but we may fittingly close this chapter with the words of his own oration at the inauguration of the Pasteur Institute:

> Two opposing laws seem to me now in contest. The one a law of blood and death, opening out each day new modes of destruction, forcing nations to be always ready for battle. The other a law of peace, work and health, whose only aim is to deliver man from the calamities which beset him. The one seeks violent conquests, the other the relief of mankind. The one places a single life above all victories, the other sacrifices hundreds of thousands of lives to the ambition of a single individual. The law of which we are the instruments strives even through the carnage to cure the wounds due to the law of war. Which of these two laws will prevail, God only knows. But of this we may be sure, that Science obeying the law of humanity, will always labor to enlarge the frontiers of life.

CHAPTER III

CHEMISTRY AND INDUSTRY

WE have already seen in the previous chapters that the study and science of chemistry has been developed along two separate lines. There is an order of mind, like that of the great Faraday, that dislikes the very thought of the application of scientific research to industry. Investigators of this type treat with scornful contempt the question: Of what good or use to mankind are your patient and exhaustive researches? Very likely Cavendish as well as Faraday was of this type but it has been shown that the application of the work of these two great masters has had a most profound effect upon industrial development as well as upon pure science. On the other hand, Humphry Davy and Pasteur took eager delight in the application of their discoveries to the everyday commercial problems of civilization.

The application of chemistry to the great basic industries upon which civilization really rests was making a precarious start during the latter part of the eighteenth century, but the French revolution dealt heavy blows to organized industry as well as to scientific research. The hurt done to the progress of science by the Reign of Terror was incalculable. The great Lavoisier was guillotined on the Place de la Revolution, now the Place de Concord in Paris, the eighth of May, 1794. The last appeal for mercy was met by his savage

judges with the famous reply: "The Republic has no need for savants." All this is well known history, but it is not so well known that another execution on the same spot, which had already taken place on the sixth of November, 1793, was destined to strike the new art of applied chemistry a rude blow which delayed its advance for many years. We are here referring to the death by the guillotine of Phillipe Egalité, the famous patriot, Duc d'Orleans, near relative of the hapless king, Louis XVI.

The alkali substance known as soda ash or sodium carbonate enters in one form or another into the manufacture of nearly every product of industry. Upon this chemical substance and its allied compounds depend the prime needs of civilization comprised, for example, in the manufacture of glass, paper and soap, as well as cotton spinning. This alkali is also equally basic with sulfuric acid in the manufacture of gunpowder and high explosives, and therefore is a war material of prime importance.

Nicolas Le Blanc (1742-1806), an immortal name in the history of chemical technology, was physician to the Duke of Orleans, and in 1787 he was attracted to the urgent war problem presented by the scarcity of sodium carbonate. Up to that time potash leached from wood ashes was the more important of the two fixed alkalies. But potash is unfitted to take the place of soda in many of the operations of peace and war, while the great drain upon the forests as a principal source of alkali could not possibly continue. On the other hand, common salt (the chloride of sodium) is abundant in many countries, while the oceans offer an inexhaustible supply. The Arabs imported soda collected as natural efflorescence in desert countries, and the ashes of certain unusual plants yielded it in an impure form known as "barilla," but there was no other source of supply.

It was natural, therefore, that men's minds should turn to common salt as a raw material. In 1775, the French Academy of Science offered a prize of 2400 Livres for the solution of this problem, and though the prize has never to this day been paid to any one, the problem was amply solved first by Le Blanc and afterwards by the Belgian Solvay brothers. In 1789 Le Blanc proposed to the Duke of Orleans that he finance a factory to manufacture soda ash from salt. Le Blanc's process converted common salt to the sulphate by a treatment with sulphuric acid, the by-product muriatic acid formed in the reaction being condensed and saved. The sodium sulphate thus formed was mixed with ground chalk or limestone and a little charcoal, and given a heat treatment which converts the sodium sulphate into the carbonate. Lunge, the great authority on alkali, states that Le Blanc's specifications for this manufacture were so clearly worked out that with the most moderate skill in building the works, pecuniary success was certain in view of the comparatively enormous price then paid for soda in the shape of barilla. With money furnished by the Duke of Orleans, a factory was erected at St. Denis and called "La Franciade." The profits were to be divided 9/20 to the Duke, 9/20 to Le Banc and his assistant Dize, and 2/20 to another assistant. The factory started and every day 5 or 6 hundred weight of soda was made. In consequence of the war with Spain, the price of "barilla" soared to 110 francs a kilo, and the prospects were joyous for the infant industry. Suddenly a series of tragedies occurred. The Duke was arrested and executed. The works La Franciade were confiscated and scattered. Le Blanc's patent which represented great value was cancelled. Le Blanc was ruined and absolutely impoverished, his beloved daughter fell ill from want and died of fright of the Terror. After lingering on

several miserable years trying vainly to get redress from one provisional government after another, Le Blanc put an end to his life with a pistol shot, but his soul went marching on. In the very year of his death (1806) an alkali works was founded in Paris, and within a twelve-month the St. Gobain plate glass works was manufacturing plate glass with Le Blanc's soda.

From that time on it became a great industry and spread rapidly into England, Germany and Austria. During three-quarters of a century the Le Blanc process easily triumphed over all its rivals, but finally was challenged and overcome by the more economical ammonia-soda process of Solvay. In this process ammonium carbonate reacts on salt brine and thus links up the manufacture of soda with the great coal distillation industry in which ammonia is a by-product. Our own great Solvay plants at Syracuse comprise some seven miles of connected buildings and give employment to many thousands of people. In its turn the Solvay process has found a competitor in the great hydro-electric methods by which the power of Niagara is converted into electrical power and salt brines converted by electrolysis into soda and chlorine. In this reaction, hydrogen gas is made as a by-product, and though as yet this hydrogen largely is allowed to escape into the air to seek the furthermost confines of the earth's atmosphere, it may eventually find a use in the service of mankind. The other by-product, chlorine, by absorption in lime makes bleaching powder which is essential to the great paper making and textile industries.

Another chemical which is basic to nearly all the great industries is sulfuric acid. Some one has suggested that the degree of a nation's civilization can be measured by the quantity of sulfuric acid which it manufactures. When native sulfur or metallic sulfide ores (pyrites) are roasted

in the air, they burn to the lower oxide of sulfur (SO_2). In order to make sulfuric acid, it is necessary to attach another oxygen atom to the molecule to form SO_3. This operation is not as simple as it sounds, and it is no exaggeration to say that the balance of trade between the nations has frequently fluctuated since the seventeenth century as the chemical methods and arts for attaching this additional oxygen atom have been developed by the chemists of the competing countries.

Joshua Ward (1685-1781) of England was the first to undertake the commercial manufacture of sulfuric acid by deflagrating a mixture of nitre and sulfur under large glass bells, so that it came to be known as oil of vitriol made by the bell or per campanum. Dr. John Roebuck (1718-1794), also in England, substituted lead chambers and although there have been many improvements, chamber acid is still manufactured at the present time. The most interesting invention in connection with the modern manufacture of sulfuric acid depends upon what is known as the contact process which we will return to shortly.

Native sulfur is found in great quantities in the neighborhood of extinct volcanic geological formations, and for many centuries most of the brimstone of commerce came from Sicily, which permitted that little Italian island to carry on a very considerable trade in sulfur with the United States. In boring deep wells in Louisiana for petroleum exploration, enormous strata of very pure sulfur was encountered, but there was no way to come at the deposit until Frasch, an American chemical engineer, conceived the idea of letting super-heated steam down the pipe to melt the sulfur, and then forcing it to the surface just as oil or water can be raised with pumps. This was a fortunate discovery for America but quite the reverse for Sicily.

We will now turn back a few years to the time of Berzelius (1779-1848) the indefatigable Swedish chemist who in 1807 devoted himself to the elucidation of the Daltonian laws of chemical combination and affinity. Berzelius saw that the exact determination of the atomic weights was a matter of fundamental importance, and for ten years, with unflagging industry and with but meager appliances (for we are told that much of his work was done in his kitchen where he was assisted by a faithful cook), he determined the atomic and molecular weights of some two thousand simple and compound bodies. In the course of these researches Berzelius noted that certain molecules that did not react or combine with each other to any extent when heated or otherwise treated would do so readily when they were in contact at the same time with a third substance, even though the third substance was not altered or changed in slightest degree during the course of the reaction. This contact action is now known as catalysis, and it has made possible some very wonderful advances and discoveries in the application of chemistry to industry. Catalyzers consist usually of metals or their salts. Faraday in studying the union of hydrogen and oxygen to form water, soon made the discovery that if these gases mixed in the proper proportion were allowed to impinge upon a small disc of clean metallic platinum, the velocity of reaction was so increased that the mixture exploded. Many workers have since been engaged in this fascinating field of research. By allowing a mixture of SO_2 and oxygen to impinge on platinum gauze, sulfuric acid is made directly by the contact process. In a similar manner, nitrogen from the air can be made to unite with hydrogen to form ammonia, and this, in turn, can be made to unite with oxygen of the air to form nitric acid. It is principally because platinum was

so needed as a catalyzer during the war that the women of America were urged to turn in their platinum mounted jewelry, while the jewelers and dentists were asked to abstain from the use of this beautiful and costly metal.

Another very interesting application of catalysis to industry is in the hydrogenation of oils. The catalytic contact of certain metals appears to stimulate the rather unreactive element hydrogen and awaken it from its normally dormant condition so that it immediately combines with other bodies, as its partner oxygen is ever prone to do. In 1903 it was discovered that the liquid vegetable fatty oil, olein, could be solidified by contact with a nickel catalyzer. By this means cottonseed and other vegetable and nut oils can be solidified and made into palatable and wholesome food products. Today, to quote a recent authority,[1] "this branch of the oil industry is growing by leaps and bounds, and its advent into the field has brought a flood of congratulations, protests and criticisms, market disturbances, and great activity among chemists to improve the catalytic materials and processes of treatment."

Although it has been so much studied, the mechanism of and reason for catalysis or contact action is not understood, so that it has been cynically referred to as the last refuge of chemists when pressed for an explanation of obscure phenomena.

One curious fact in connection with catalysis should be referred to before leaving the subject. Since the days of Pasteur, it has been known that living cells, such as yeasts and bacteria, produce fermentation and various biochemical reactions, and it is now known that in many cases the expressed and even the dried juices of these cells, products known as "enzymes," will carry on precisely the same re-

[1] *Hydrogenation of Oils.* Carleton Ellis. Van Nostrand (1914).

actions as the living cells themselves. It does not in the least surprise us that living cells can be poisoned and anæsthetized. A pinch of arsenic will kill even a man, a few drops of chloroform will put him to sleep, and much less of these drugs will produce the same effect on yeast cells. The enzymes, however, which cannot by any stretch of the imagination be called living beings can also be killed and inhibited by the same means as the living cells. But now comes the surprising fact: A catalyzer consisting of a bit of clean metal such as platinum or nickel can be poisoned and in many cases by impurities in the reacting gases or bodies that would be also harmful to living cells. There is a great mystery hidden in these observations, which may in its final elucidation by science shed some light on the origin and nature of life, if not indeed of death. We have much ground to cover in the application of chemistry to industry, and we must leave this fascinating and very modern field of scientific inquiry for more practical subjects.

The manufacture of iron and steel is the one great basis of civilization. Deprived of iron (and we will use this word generically to include steel and its alloys), man would revert at once to the nomadic condition of his earliest ancestors. Imagination can no longer contemplate an ironless world nor conceive of what life would be like without it. Our own distinguished American metallurgist, Henry M. Howe, has introduced his article on iron and steel in the Encyclopedia Brittanica in the following interesting way:

Iron, the most abundant and the cheapest of the heavy metals, the strongest and most magnetic of known substances, is perhaps also the most indispensable of all save the air we breathe and the water we drink. For one kind of meat we could substitute another; wool could be replaced

by cotton, silk, or fur; were our common silicate glass gone, we could probably perfect and cheapen some other of the transparent solids; but even if the earth could be made to yield any substitute for the forty or fifty million tons of iron which we use each year for rails, wire, machinery, and structural purposes of many kinds, we could not replace either the steel of our cutting tools or the iron of our magnets, the basis of all commercial electricity. This usefulness iron owes in part, indeed, to its abundance, through which it has led us in the last few thousands of years to adapt our ways to its; but still in chief part first to the single qualities in which it excels, such as its strength, its magnetism, and the property which it alone has of being made at will extremely hard by sudden cooling and soft and extremely pliable by slow cooling; second, to the special combinations of useful properties in which it excels, such as its strength with its ready welding and shaping both hot and cold; and third, to the great variety of its properties. It is a very Proteus. It is extremely hard in our files and razors, and extremely soft in our horse-shoe nails, which in some countries the smith rejects unless he can bend them on his forehead; with iron we cut and shape iron. It is extremely magnetic and almost non-magnetic; as brittle as glass and almost as pliable and ductile as copper; extremely springy, and springless and dead; wonderfully strong, and very weak; conducting heat and electricity easily, and again offering great resistance to their passage; here welding readily, there incapable of welding; here very infusible, there melting with relative ease. The coincidence that so indispensable a thing should also be so abundant, that an iron-needing man should be set on an iron-cored globe, certainly suggests design. The indispensableness of such abundant things as air, water and light is readily explained by saying that their very abundance has evolved a creature dependent on them. But the indispensable qualities of iron did not shape man's evolution, because its great usefulness did not arise until historic times, or even, as in case of magnetism, until modern times.

The words "iron" and "steel" are often very loosely used, and it may be as well at this place to discuss their meaning. Unfortunately, considerable difference of opinion exists, even amongst metallurgists, on this subject of definition. According to one school, any metal melted in a steel making furnace, that is poured into and cooled in a mould, is steel, while any metal that is hammered and worked down from the one or other raw material in a pasty condition is iron. According to this rather narrow view, if the so-called puddling process should be entirely abandoned, iron as a commercial product would become as extinct as the dodo. Strictly speaking, in a dictionary sense, steel is iron combined with carbon to a greater or less extent, while iron does not or should not contain combined carbon. These latter definitions will be adhered to for our present purposes.

In the earliest recorded times, man smelted iron by mixing the ore which is found in nature as an oxide with coal or charcoal, and heating the mixture, using rude bellows, at the same time working and hammering the hot, pasty mass until the oxygen was entirely removed by uniting with the carbon. There is a wonderful column or monument of iron at Delhi in India, which was made in this way many years before Christ. As the centuries went by many improvements in manufacturing iron and its conversion into steel were made, as the work of the old armorers, which has come down to us, bears witness to.

In 1856 Henry Bessemer, an Englishman, invented the process of blowing air through molten pig iron in enormous pear-shaped vessels, thereby converting large quantities of the metal into steel in a remarkably short time, the necessary high heat being obtained by the burning of the impurities contained in the pig iron instead of by the use of

costly fuel. This process revolutionized the art of steel making and produced the most profound effect upon civilization. From this time on, the building of railroads began to open new empires, while steel ships carried the world's commerce throughout the seven seas. This in turn stimulated the necessity which is in truth the mother of invention, and the electric telegraph and many of the other wonderful inventions of the nineteenth century quickly followed.

The open hearth process, first installed by the Martin brothers in France and at about the same time by Siemens in England, furnished an almost equally economical process for making steel from even more impure ores, and for that reason is at present challenging the Bessemer converter's supremacy in its own field. For most purposes today, open hearth steel is considered superior to Bessemer.

Up to a comparatively recent period the open hearth has been considered as exclusively a steel making process. The purer carbonless irons which are superior to ordinary steels for a great many purposes were mainly imported into the United States from Norway and Sweden where the lower labor costs permitted the carbon, manganese and other impurities to be eliminated to the lowest possible minimum. It is a matter for congratulation that we now have worked out an American process for making commercially pure iron in the open-hearth furnace on the same large scale of operation commonly used in the manufacture of ordinary mild or low carbon steels. This American process, now some ten years old, has proved itself to be an actual contribution to the metallurgical art and has exerted a stimulating influence on the production of high quality metals, not only from a slow rusting standpoint but also because extreme purity of product is desirable for a great many special purposes.

Next to iron and steel in the order of importance among the basic industries of man, come the ceramic arts in which we may include all objects fashioned of clay and burned in kilns. We may well be astonished at the proficiency of the ancient Greek civilization in the control of the chemical processes by which they manufactured their wonderful glazes which it is doubtful if modern ceramic chemists could duplicate. The study of the black and red figured pottery and fragments which have been excavated after remaining buried for centuries in the earth has become a special branch of archeology, and shows by the test of time the wonderful durability of the ancient pottery and glazes. The marvelous china and porcelain of the Middle Ages, with their beautiful colors and glazes, have excited the admiration of mankind and stimulated the zeal of collectors. These products serve to show the results that the purely empirical chemistry of the earlier days was able to achieve in the hands of the ancient clay worker, more especially among the Chinese.

Among the many discoveries of the nineteenth century which profoundly influenced the progress of civilization was the discovery by Joseph Aspdin of Leeds in England of Portland cement. The only connection between Portland cement and the place Portland is that when mixed with water in the proper proportions, it sets or hardens into a mass resembling natural stone quarried at Portland, England. Hydraulic cements which will harden with water were in use many years before Aspdin's discovery, and the ancient Romans knew and used them under the name of Roman cements. These were made of Vesuvian lava cooled and ground either with or without lime, but the modern method, carefully controlled by chemical analysis, calcines a definite

mixture of clay and limestone, and, being an artificial product, it is of substantially uniform composition and quality. And what a wonderful material this is which industrial chemistry has placed in the hands of the engineer. With it he constructs foundations underneath the seas and builds railroads above them, he bridges the rivers and dams them for the development of power, designs and constructs monumental buildings forty stories high, constructs ocean-going ships, and altogether takes upon himself the attributes of a creator, outdoing and out-distancing Nature herself.

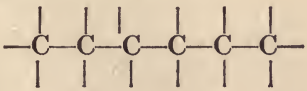
We must now return for a moment to some work that was being carried on in the laboratories of the Royal Institution of Great Britain in 1825. In that year, Michael Faraday was investigating illuminating gas obtained by distilling certain oils. In the course of this research, Faraday discovered a mobile, liquid hydrocarbon which was found to consist of a union of six atoms of carbon with six atoms of hydrogen (C_6H_6). This was a momentous discovery as it turned out, although as it was somewhat outside Faraday's principal lines of research which were mainly electrical and electro-chemical, it is probable that it did not particularly interest him. In any case, we hear no more of it until 1833 when Mitscherlich (1794-1863), a German chemist, prepared the same hydrocarbon by heating benzoic acid obtained from an oriental gum known to the trade as gum benzoin or dragon's-blood (Styrax benzoin). Mitscherlich immediately named the hydrocarbon benzin or benzine. The following year Liebig proposed the name benzol from the Latin word oleum, oil. Again we hear little of this new hydrocarbon which was destined to exercise so profound an influence upon the history of the human race, until 1845 when A. W. Hofmann (1818-1892), a German chemist,

established in England by the Prince Consort, rediscovered it in coal tar and called it benzene.

Little did anyone suppose in 1850 that this rather malodorous liquid hydrocarbon of Faraday, Mitscherlich and Hofmann was to furnish the basis for the great coal tar industry with its dyes, medicinals, and explosives, and was destined to make the greatest war of mankind possible even if it did not directly contribute to its causes, through the international jealousies and the struggle for mastery which it occasioned.

The atom of carbon is quadrivalent, that is to say, it has four linkages or points of attraction for other atoms, and is generally written:

But the most interesting characteristic is the ability of carbon to link up in chains, such as:

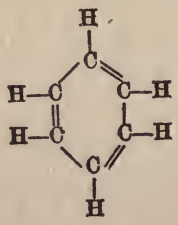


This characteristic, in which the carbon atom may be said to be unique among the elements, permits the endless variety of architecture in the structure of the molecules of organic bodies. All this will be discussed in detail in the next chapter.

We have in a previous paragraph noted Professor Howe's suggestion that the appearance of iron-needing man on an iron-cored globe suggests design. What shall we say, then, of the possibility that the unique self-linking property of the carbon atom was especially and purposely conferred? Without this property, life on this planet might exist in

some primitive form, but most certainly the evolution and development of life and civilization could never have gone on. Why the atoms of other elements should not also possess this characteristic, is as inexplicable as that iron should be the only one capable of appearing as a temporary or permanent magnet, another phenomenon on which the whole structure of modern civilization is based.

We have already seen that benzene [2] or benzol is a chemical compound made up of molecules of the composition C_6H_6. In 1858 Kekule, a German chemist and pupil of Liebig, published a paper in which he discussed the quadrivalence and linking power of the carbon atom, and this led up to the announcement in 1865 of a theory which has been called "the most brilliant piece of prediction to be found in the whole range of organic chemistry." This theory set forth that the six atoms of benzene are connected in a closed chain or ring formation which for convenience is expressed in a hexagon formation as follows:

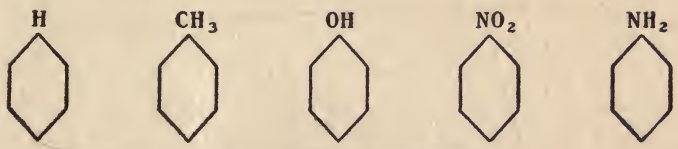


The hydrogen atoms in benzene are highly reactive and can be easily substituted or linked onto by other atoms or groups of atoms, while the carbon ring is extremely stable and difficult to break down. An immense amount of labor

[2] The word benzine is now applied to the lightest fractions of the distillation of petroleum. Benzine is not a distinct chemical compound, as is benzene, but is a mixture of hydrocarbons of variable composition. There is much confusion in the use of these words.

has been expended upon Kekule's theory, in the effort to test it or to improve upon it, but so far it has stood the test of time. It may truly be said that all the great discoveries in organic chemistry of the latter half of the nineteenth century, including the development of the enormous coal tar dye, explosive and medicinal industries, have been built up on the benzene ring structure.

Toluene, a less volatile liquid than benzene, is also obtained from the distillation of coal. This is simply benzene with one of the hydrogen atoms replaced by a methyl group (CH_3). We also obtain phenol, with one of the hydrogens replaced by hydroxyl (OH). By treating benzene first with nitric acid to make nitro-benzene, and then with a reducing agent, which substitutes hydrogen for oxygen, we get aniline. These bodies chemists now graphically represent as:



These bodies are the building blocks of the organic chemist, the starting points from which he will build you out of black, viscid, ill-smelling coal tar, to your orders and demands, beautiful colored dyes, the delicate perfumes of the flowers, the most terrible high explosives, anæsthetics to put you to sleep, or stimulants to excite your organs to renewed activity.

The coal tar dye industry had its first real beginning in 1856 when Sir William Perkin (1838-1907), then a lad of eighteen who had been working as an assistant to Hofmann, the great German professor of chemistry at the Royal College of Chemistry in London, made an accidental discovery

which astonished the world. We are told that, "devoting his evenings to private investigations in a rough laboratory fitted up at his home, Perkin was fired by some remarks of Hofmann's to undertake the artificial production of quinine." In this attempt he was unsuccessful, but he stumbled on something far more important. Taking aniline as his raw material, he was treating it with certain chemicals when he obtained a soot black precipitate which is now the aniline black of commerce and with which, or derivatives of which, nearly all of our black textiles are dyed. Going a step further, Perkin discovered the aniline derivative, aniline blue or mauve, the first commercial aniline dye, which was regularly manufactured at Harrow, England, by the discoverer in conjunction with his father and brother, in 1857.

In 1834, however, a German chemist named Runge had also accidentally isolated from coal tar a substance which produced, when treated with chloride of lime, a beautiful blue color which he named Kyanol. The significance of this discovery does not seem to have been appreciated, or the Germans might have preceded the English into this field which they subsequently preëmpted. In 1841, Fritsche, another German, showed that the blue vegetable dye from India, known as indigo, when treated with caustic potash yielded an oil which he called aniline, from the Latin name of the indigo plant, Indigofera Anil. The word anil was in turn derived from an old Sanscrit word *Nila*, meaning blue. There are now hundreds of aniline dyes of all possible shades of beautiful colors, manufactured from coal tar, but it is an interesting fact not generally known that aniline, a yellowish oil, derived its name from indigo blue many years before Perkin stumbled on his famous aniline blue named "mauve."

It is not the purpose of these lectures to go very deeply

into the chemical processes by which the coal tar intermediates are changed into dyes, medicinals, perfumes, and explosives, but we have covered our subject sufficiently to show the wizardry of chemistry that can almost in a day's time derive at will from a sticky, stinking mass the delicate perfume of the violet, the beautiful color of a woman's dress, or the little tablet of aspirin that relieves human pain. As the author has previously put it:[3] "The red silk parasol of a summer beach, and the red wound of war have a common origin in that black, sticky mass."

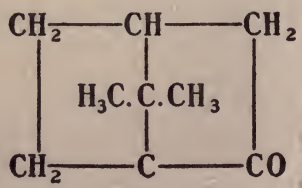
Either directly or indirectly, chemistry as applied to industry affects the conditions and well being of every home. The clothes we wear, the food we eat, the utensils we handle it with, the materials with which we are housed or transported from place to place, the medicines we depend upon in the struggle with disease and death, are all dependent on strictly chemical industries.

One of the wonderful accomplishments of modern chemistry is the synthesis from the elements or from some common raw materials of products useful to civilization, which have hitherto been exclusively produced by organic life processes. True synthetic indigo is now made from coal tar napthalene or from aniline. At the risk of, or perhaps for the purpose of, provoking a smile, we might follow a Biblical precedent and record the synthesis of indigo in this wise: Napthalene begat Phthalic anhydride. Phthalic anhydride begat Phthalimide. Phthalimide begat Anthranilic acid. Anthranilic acid begat Phenyl-glycine-ortho-carboxylic acid which begat indoxyl which begat indigo which is written:

$$C_6H_4\begin{matrix}NH\\CO\end{matrix}\!\!>C = C\begin{matrix}NH\\CO\end{matrix}\!\!>C_6H_4$$

[3] *Chemistry and American Industry.* Jour. Franklin Inst., May, 1017.

Or, again, take camphor which is gum from a tree that grows principally in Formosa and is a Japanese monopoly, which costs at present something more than $3.00 a pound. Most people think of camphor as something mainly useful in keeping moths away from their winter clothes in summer time. But camphor mixed with nitrated cotton or nitrocellulose makes celluloid and celluloid makes moving picture films, and the populations of the earth have decided that though they might at a pinch do without sugar or do without bread, they cannot do without "movies." So the Japanese camphor trees are milked and mulcted, for the amusement of the millions must not be interrupted. Moreover, camphor is needed to make artificial leather, and artificial leather is necessary to make Ford cars, and the time does not seem far distant when every man, woman and child will need at the very least a Ford car. Let us see what the chemist is doing about this. Camphor trees do not thrive very well in our United States, but pine trees, God bless them, do. The pine tree yields turpentine; turpentine treated with hydrochloric acid yields pinene hydrochloride, and this can be changed under catalysis to a complicated molecule known as isoborneol, and this by oxidation yields synthetic camphor, identical in every respect with natural camphor except for the curious fact that it is optically inactive, while all the natural products rotate a polarized light ray. There follows a picture of the structure of the camphor molecule as chemists write it:



Of all the numerous organic syntheses that chemistry has achieved, none is more interesting or more important for the future than that of India rubber. By the action of heat on turpentine, a volatile liquid called isoprene is formed. In 1892, Sir William Tilden, an English chemist, read a paper before the Philosophical Society of Birmingham, in which the following paragraph occurred:

I was surprised a few weeks ago at finding the contents of the bottles containing isoprene from turpentine entirely changed in appearance. In place of a limpid colourless liquid the bottles contained a dense syrup in which were floating several large masses of solid, of a yellowish colour. Upon examination this turned out to be india-rubber. . . . The artificial, like natural, rubber appears to consist of two substances, one of which is more soluble in benzene or carbon bisulphide than the other. A solution of the artificial rubber leaves on evaporation a residue which agrees in all characters with a similar preparation from Para rubber. The artificial rubber unites with sulphur in the same way as ordinary rubber, forming a tough elastic compound.

Naturally, if synthetic rubber is to become an article of commerce and compete with Para or plantation rubber, a cheaper and more abundant raw material than turpentine had to be found. The Germans through their great *Badische Anilin und Soda Fabrik* worked out a method for converting certain fractions of petroleum distillation into isoprene and at the International Congress of Applied Chemistry, held in New York in 1912, they exhibited a huge slab of synthetic rubber as well as automobile tires made from it. There have also been stories told that ways have been discovered for converting potato and other cheap vegetable starches into isoprene. If this is true, the great automobile industry may find itself in the not distant future indebted to the humble potato.

This is a wonderful field of research, and perhaps enough has been said to show that a research chemist's work is like a fascinating play. Perhaps this is why the American public rewards the chemist so stingily, feeling that the work is its own reward and that the chemist does not need to eat. As Pope has put it in his Essay on Man:[4] "The starving chemist in his golden views supremely blest."

[4] *Essay on Man*, ii, 269.

CHAPTER IV

CHEMISTRY AND WAR

AT the meeting of the British Association for the Advancement of Science in 1898, Sir William Crookes in the presidential address gave emphatic utterance to a warning on the world's food problem. He held that there was not enough fixed nitrogen available in the nitrate beds of Chile to supply the wheat and other grains which the populations of the future would require. As a well known scientific writer has expressed it:[1]

> William Crookes' disquieting message of rapidly approaching nitrogen starvation did not cause much worry to politicians, they seldom look so far ahead into the future. But to the men of science it rang like a reproach to the human race.

In spite of this statement, the politicians and militarists of Germany had been for many years very keenly aware that as long as the world's supply of fixed nitrogen was confined to the western coast of South America, no nation or group of nations who did not control the sea could hope to succeed in modern warfare either in offense or defense. At the time of the Moroccan dispute between Germany and France in 1911, it will be remembered that England had established an entente with France, and the stage seemed set for war. The crisis passed, however, and men everywhere

[1] L. H. Baekeland, Chandler Lecture, 1914.

said that war between the great nations had become impossible on account of the vastness of the scale on which it would have to be waged. It was further stated that the great banking interests of the nations had met and pronounced the impossibility of financing modern warfare. Thus were men's minds gradually lulled to sleep again so that preparedness for national defense among the English speaking peoples became a jest and a reproach. As a matter of fact, in 1911 the dogs of war, though straining at their collars, were held in leash simply because the great German chemists were obliged to notify their government that their researches and plans for the fixation of atmospheric nitrogen, although approaching their fulfillment were as yet incomplete.

Let us see what evidence exists to justify the above statements. In September of 1912, one year after the Agadir incident at Morocco, the triennial meeting of the International Congress of Applied Chemistry was held in New York. At this meeting one of the official German delegates, Prof. H. A. Bernthsen, in the course of his address, said:

I propose, however, today to deal, from my own direct experience, with the development of the problem for the synthetical manufacture of ammonia from its elements. A few years ago the solution of this problem appeared to be absolutely impossible. It has recently been the object of very painstaking investigations by Prof. Haber and the chemists of the Badische Anilin und Soda-Fabrik, and numerous patents have been taken out with reference to the manufacture. Apart from what is already published in this way, however, we have refrained from any other announcements until we were in a position to report something final with reference to the solution of the technical question. This moment has now arrived, and I am in the agreeable position of being able to inform you that the said problem has now been solved fully on a manufacturing scale, and that the

walls of our first factory for synthetic ammonia are already rising above the ground at Appau, near Ludwigshafen-on-Rhine.

This statement was received with *applause* by British and American scientists (save the mark).

The walls of that first factory that were rising above the ground in 1912 had risen to great heights by 1914 and the whisper went forth in Germany that the chemists were ready. "Der Tag" had arrived. But to quote Dr. Baekeland again:[2]

Do not reproach chemistry with the fact that nitrocellulose, of which the first application was to heal wounds and to advance the art of photography was stolen away from these ultra pacific purposes for making smokeless powder and for loading torpedoes. Do not curse the chemist when phenol which revolutionized surgery, turned from a blessing to humanity into a fearful explosive after it had been discovered that nitration changes it into picric acid. Let us hope in the meantime that war carried to its modern logical gruesomeness, shorn of all its false glamor, deceptive picturesqueness and rhetorical bombast, exposed in all the nakedness of its nasty horrors, may hurry along the day when we shall be compelled to accept means for avoiding its repetition.

The various methods which have been worked out in Germany and elsewhere for fixing the nitrogen of the air may be grouped in three classes. (1) Those which seek to combine nitrogen with oxygen directly by means of powerful electric sparks and arcs, the electrical energy to produce which must usually be derived from extensive and expensive water powers. At these so-called hydroelectric plants nitric acid and nitrates may be directly synthesized. (2) Those which catalytically combine nitrogen and hydrogen to form

[2] L. H. Baekeland, address before Am. Chem. Soc., Seattle, Wash., 1915.

ammonia, which may then be further oxidized to nitric acid, and (3) those processes which combine nitrogen with carbon to form cyanogen (CN) or cyanamid (CN_2) which yield by suitable treatment ammonia and hence nitric acid and nitrates. Before any person unfamiliar with chemical technology can understand all that is involved in the subject of the fixation of atmospheric nitrogen, it will be necessary to learn something of the nature and character of this gaseous element which constantly surrounds us in the air we breathe, but which no man has ever seen except when it has been artificially liquified under the action of intense cold at high pressures. In 1916 the author presented a paper before The Franklin Institute [3] on *The Rôle of Chemistry in the War.* This paper received the honor of being promptly reprinted by special enactment of the United States Senate as Senate Document No. 340. To avoid repetition, a few paragraphs from this paper are quoted:

The human race is living at the bottom of an ocean of atmosphere some six to seven miles deep. Although it is not always realized by the unscientific mind, this aerial sea has weight and exerts a pressure upon all bodies of approximately 15 pounds to the square inch. Roughly speaking, and disregarding a small amount of rare gases and impurities, the air consists of about one-fifth oxygen and four-fifths of the inert gas nitrogen.

Every intelligent person knows that oxygen is the breath of life, and that nitrogen serves the purpose of just sufficiently diluting the oxygen so that the combustion of waste carbon conveyed by the blood to the body tissues goes on at the steady rate which conforms to the life processes of all animals. With this general knowledge in regard to the element nitrogen, the ordinary, well-informed, non-technical man rests content.

[3] *Jour. Franklin Inst.,* Feb. 1916.

Educated people are, of course, aware that fixed nitrogen in combination with carbon, hydrogen, and some few other minor elements is built up by vegetable life and is in turn, assimilated into the bodies of animals, thus supplying our food of almost every variety. It is also fairly well understood that in the processes of digestion the complex nitrogenous bodies built up by plant life are broken down to simpler forms, in part supplying animal life energy and in part being voided by the animal, the manurial nitrogen products going back to the soil, thus completing what is known as the nitrogen cycle, caught in the wheel of which all material life, including the much-vaunted culture and progress of modern civilization, hangs suspended.

One thing that is not very generally apprehended by educated people, however, is that without fixed nitrogen in great abundance mankind could not wage war upon one another under modern conditions. Ever since gunpowder replaced the bow and arrow, fixed nitrogen has been used by man to hurl destructive missiles at his adversaries. In fact, it should be stated that no explosive substance has ever been used in peace or war, which did not depend for its activity on the extraordinary properties of the element nitrogen, which, as the major constituent of the air we breathe, could almost be said to content itself with the inert and pacific rôle of toning down the activities of its restless neighbor, oxygen.

It becomes evident, from what has been said, that there must be some vital and important difference in character or quality between what may be termed fixed and unfixed nitrogen. In other words, it should be understood that all life and phenomenal existence, on this planet at least, depend upon the simple fact that the element nitrogen is able to assume two rôles, in one of which it is unfixed, inert, sluggish, and slow to enter into combination with other elements, and in the other of which it is active, reactive, restless, ever ready to break down into new combinations, absorbing and giving out enormous energy as the restless changes take place. whether the changes take place in a measured and orderly fashion, as in plant-cell growth and animal digestion, or

with the most sudden and terrible violence, as in the case of high explosives, the energies either absorbed or released are equally potent and measurable. The celebrated chemist Berzelius once said of the element nitrogen as it occurs in the air, "It is difficult to recognize by any conspicuous property, but can only be recognized by means of properties which it does not possess."

Before pursuing our subject further it will be necessary to make quite clear what is meant by inert, unfixed nitrogen and active or fixed nitrogen. This explanation must be made in such a way that all apparent contradictions will immediately disappear. Gaseous nitrogen as it exists in the atmosphere has been proved by scientific methods to consist of a molecule made up of two atoms bound together by the equivalent of three bonds of affinity. What is meant is made clearer if we write a sort of alphabetical expression of the inert nitrogen molecule, as follows:

$$N \equiv N$$

It should not be supposed that the three bonds are actually arms or linkages holding the atoms together; they simply represent actually existent atomic forces, so that we may say that the element nitrogen is trivalent. In the same way we know that the element hydrogen is univalent, and we may express this by writing H—H, for the molecule of hydrogen is also known to be diatomic.

Now, suppose that by some means it is desired to combine or fix nitrogen to hydrogen; it is at once apparent that we should have to expend energy to tear apart the molecular bonds before we can fix the two elements together. In other words, the N≡N would have to pass through the condition N≡ and ≡N. Similarly, the H—H would have to split up into H— and —H. Subsequently the two elements might combine to form ammonia:

$$\begin{array}{c} \text{—H} \\ \text{N—H} \\ \text{—H} \end{array}$$

For the purpose of this paper it is not necessary to go

deeper into the combining valences of the different elements which it will be necessary to discuss. Only the simplest combination of nitrogen and hydrogen, viz., ammonia, has been mentioned in order to show the difference between fixed nitrogen and the inert or unfixed state of this gas as it exists in the air, with all its chemical affinities self-satisfied; in short, in the condition $N \equiv N$. If, however, this union is torn apart, $N\equiv$ is in an actively unsatisfied state and is prepared to fix itself into myriads of combinations with other elements. In other words, the molecule of nitrogen is quiet and well behaved, whereas the free atom of nitrogen is dynamically and even, in some combinations, very terribly reactive. It is this underlying chemical fact that has enabled men to slaughter and destroy each other on the gigantic scale now being demonstrated.

Those who have followed this explanation will readily see that it is not possible to maintain nitrogen in the condition of free unsatisfied atoms $N\equiv$, for the simple reason that these atoms would return to the stable, quiescent molecule ($N\equiv N$), possibly with explosive energy. In order to take advantage of the reactive condition, it is necessary to lightly fix the nitrogen atom to some other atoms or groups of atoms in such a manner or in such a combination that the nitrogen at a blow can be suddenly released. Let us take the simplest example of what is meant. By an experiment so simple that the merest tyro in chemistry can perform it, ammonia can be made to react with the univalent element iodine to form the compound known as nitrogen iodide, in which iodine is made to replace the hydrogen, so that $N\begin{matrix}-H\\-H\\-H\end{matrix}$ becomes $N\begin{matrix}-I\\-I\\-I\end{matrix}$. Now, this nitrogen iodide is a brown powder, which when carefully dried, will remain innocently enough, resting quietly unchanged. If, however, we even so much as tickle this brown substance with a feather, or even if a door in the building in which it lies is rudely slammed, a terrible detonating explosion will occur, and the air will be filled with the stifling, violet-colored fumes of iodine. A

quantity of this powder which could be heaped on the surface of a small silver coin would be sufficient to wreck everything in its neighborhood.

Whence this extraordinary energy? The thermodynamics of this and similar reactions are too complicated and mathematical to discuss here, but it is easy to see that the atomic forces at work in the sudden liberation of free nitrogen and iodine atoms, and their instantaneous rearrangement into inert molecules, involve enormous energy effects. Of course, nitrogen iodide is too treacherous a substance to be used as a high explosive, for in the dry condition the merest jar would cause it to detonate. It is obvious, therefore, that it has been the task of the chemist to find ways of locking nitrogen to other elements or groups of elements, with the result that it will be fixed tightly enough so that premature explosion will be avoided, but not so tightly but that it can be exploded by small quantities of more reactive nitrogen compounds made up in the form of percussion caps or detonators. All modern high explosives are just such chemical combinations of nitrogen as this, and we have, among others, nitro-glycerin (dynamite), nitrocellulose (guncotton), trinitro-phenol (picric acid), nitrogelatine, trinitro-benzene, trinitro-toluene, etc. Masked under such trade names as lyddite, melinite, turpenite, cordite, etc., these nitrogen compounds are products of modern chemistry known and used by the armies and navies of the world.

Now that we have learned something of the importance of fixed nitrogen in connection with the food problem which is always with us, and the war problem which has passed, we may hope, for this generation if not forever, let us see what the present status of the problem is as far as our own country is concerned. In Norway where hydroelectric power is abundant and requires much less capital to develop than with us, the arc processes are already competing with Chilean saltpetre. What Germany will do with her war

plants in the future remains to be seen.[4] For ourselves, we spent millions of dollars on this problem, subsequent to our entry into the war, which except for a certain value in ex-

[4] Synthetic Nitrogen in Germany

Lieut. R. E. McConnell has recently inspected the Haber plant at the Oppau works of the Badische Soda u. Anilin Fabrik near Ludwigshafen on the Rhine. As the Germans raised strong objections to detailed examination, he was able to spend only three days at the factory and was not permitted to view the plant in actual operation. During the year ended Nov. 1, 1918, this plant produced 90,000 long tons of fixed nitrogen, i.e., its capacity was equal to one-fifth of the total three million tons of nitrate supplied by Chile to the entire world during the same period, and ten times that of the Haber plant installed by the United States Government at Sheffield, Alabama. If to this output be added the reported production of 125,000 tons at a factory near Halle, the combined output would be equal to one-half that of the total supply from Chile.

It has been officially stated in the Reichstag that 400,000 tons of combined nitrogen was produced in Germany in 1916. However this may be, it seems certain that Germany is capable of exporting nitrogenous compounds in amounts approximately equal to her pre-war normal consumption of 750,000 tons of Chilean nitrate. The producing capacity of the Oppau works at the present time is estimated to be:

Oppau Plant	Tons per annum	Tons combined nitrogen per annum
Ammonium nitrate	10,000	3,450
Sodium nitrate	130,000	21,410
Nitric acid (100%)	40,000	8,890
Ammonia (liquid)	40,000	32,900
Total		66,650

The cost of the plant is stated to have been between 5 and 10 million sterling; today a similar plant in the United States would cost at least £13,000,000, says the "Journal of Industrial and Engineering Chemistry." The personnel of the factory comprises 1,500 laborers, 3,000 mechanics, 350 clerks and 300 chemists. The daily consumption of fuel is 1,750 tons of lignite and 500 tons of coke, and the total cost per diem is about £11,000, including allowances for depreciation, etc. Assuming that in normal times the plant would be shut down for repairs, etc., during one-tenth of the year, the total cost would be £11,600, and the output 553,000 pounds of combined nitrogen, i.e., the production cost would be about 5½d per pound, equivalent to Chilean nitrate at 0.87d per pound. (The latest reported price of the latter is 9s per quintal, say 1d per pound in Chile.) If all the ammonia produced were converted into 100 per cent nitric acid, the author concludes that the plant could produce acid at a cost not exceeding 3 cents (1½d) per pound. The pre-war cost in the United States of this acid made from Chilean nitrate was 5-6 cents per pound (2½d-3d), and today it will be considerably higher. Finally, the author indicates the serious consequences which would result from Germany acquiring a monopoly of these nitrogen compounds.—*Drug & Chemical Markets,* Nov. 19, 1919.

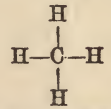
perience, have been so far almost entirely wasted. The normal imports of Chilean nitrate into this country total nearly 600,000 tons yearly, yet there is now in actual operation (January, 1920) just one plant for the fixation of air nitrogen, and this has a maximum production of less than 5000 tons of nitric acid per year. This is a privately owned plant operating on the arc principle of fixation. Canada has an extensive plant for the manufacture of cyanamid, as have also Norway, Germany, Spain, France, Italy, Great Britain, and Japan.[5] For ourselves, let us hope that no untoward destiny will ever throw us into conflict with any nation or group of nations capable of gaining control of the highways by land or sea, that lead to the sources of fixed nitrogen. If that day arrives in advance of the development of our own adequate processes of fixed nitrogen supplies, the pangs and penalties of once proud Russia will be ours.

The element carbon, unlike nitrogen, does not appear in nature in the gaseous form. It is familiar to everyone in an impure form as coal, as charcoal, and graphite, and in its pure crystallized form as the diamond. Considered as an atom in its chemical sense it is highly reactive and ever ready to combine with other atoms and groups of atoms to form the endless variety of organic forms which make up the visible universe. The most characteristic attribute of the carbon atom is its power and tendency to link up with other carbon atoms, thus permitting an infinite variety of molecular architecture. It will be necessary to follow this statement a little further, on account of its bearing on the rôle of chemistry in the war.

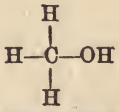
[5] The present status of this important development of chemistry and chemical engineering is too detailed for insertion at this place, but for those who are interested a brief report as of January, 1920, is printed in Appendix A.

We have seen that the free atom of nitrogen is called trivalent and is written $N\equiv$. Similarly, the free atom of carbon is known to be quadrivalent and might be written $C\equiv$. As a matter of fact, however, the quadrivalence of the carbon atom is expressed in the following form:

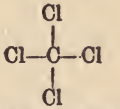
Really the carbon atom with its four bonds is thought of spacially as being at the center of a pyramid or tetrahedron. For our present purpose, however, we need not confuse ourselves with this conception, but think of it as written above. The point to be understood is that the free affinities of the carbon atom are easily saturated with other atoms or groups of atoms, as, for instance, in the following compounds:



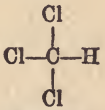
Marsh gas (methane)



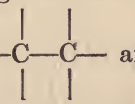
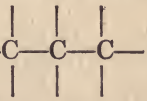
Methyl alcohol

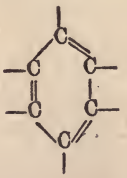


Carbon tetrachloride

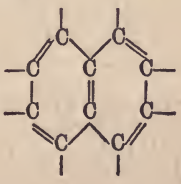


Chloroform

But the most interesting characteristic is the ability of carbon to link up as in  and  and so on until we reach a string or nucleus of six atoms, when in many cases the string acts as though it were unwieldly and, like a snake with its tail in its mouth, links up into form of a ring known as the benzene ring, and written:



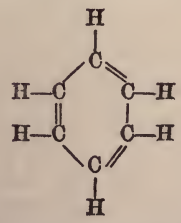
or further into double or even triple rings



It may appear to the layman that we are involving ourselves pretty deeply in advanced chemistry, but we must be patient, because we are getting close to the secret of modern warfare as it is controlled by high explosives. We are also getting close to the secrets of the dye industry and modern medicinals, which subjects have been much discussed in this country since the outbreak of the war.

Benzene has already been referred to in an earlier paragraph as a by-product of the coke and gas industry. It is a limpid liquid substance which closely resembles gasoline in odor and properties. If cheap enough, it could be used in automobile engines, but its price before the war in this country was about 30 cents a gallon, which was prohibitive of its use for this purpose. It is an important raw material for the manufacture of high explosives, dyes, synthetic medicines, phonographic records, etc. Benzene has the chemical formula C_6H_6, and is to be considered as a ring of six carbon atoms attached as shown above, with one hydrogen atom fixed to each carbon. For the sake of brevity and simplicity, chemists no longer take the trouble to write in the carbon or hydrogen atoms into their ring formulæ, these being assumed, only the significant substituting atoms being placed and written in. Thus, for instance, the benzene, or, as the Germans call it, the benzol ring, is expressed by writing:

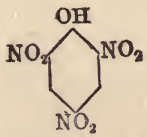
instead of the more cumbersome



Now, suppose by treating benzene with certain chemicals

we replace one of the hydrogens by the group of atoms OH, we get

This body is carbolic acid, known to chemists as phenol. It was this substance that we have read in the newspapers Thomas A. Edison needed for making phonograph records after the German supplies ceased, and which he was able to make as soon as the recovered benzene began to be available from the American gas and coke plants. Now, if we start again with phenol and treat it with nitric acid in a special manner, we make trinitro-phenol, or picric acid, an intensely yellow substance which is used as a dye base and is also one of the most deadly of the high explosives. We write the formula of picric acid



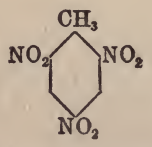
and designate it as a 2, 4, 6 substitution product, for the group or radical NO_2 must fix to just the right points in the carbon ring, or we should not get picric acid, but something else. Perhaps we have now succeeded in getting a glimpse into the wonderful molecular architecture that has been patiently worked out by chemists for the use of man in the arts of peace and war. Untold numbers of tons of picric-acid mixtures under the names of melinite and turpenite were shot off on the European battlefields.

Looking at the graphic representation of the picric-acid

molecule written above, it requires but a slight effort of the imagination to picture what takes place when this molecule is suddenly shattered into its elements. Large quantities of hot nitrogen, hydrogen, and oxygen atoms are instantly set free, seeking to expand and satisfy their various affinities. The chemical forces of disruption and rearrangement are titanic and when directed to that end scatter death and destruction round about.

Picric acid, when dry, melts down quietly at a little above the water-boiling temperature, with little danger of explosion unless it is detonated by something else. It is usually melted down with rosin or some other body which is used to dilute it. It is these other bodies which are partly responsible for the dense clouds of black smoke formed when shells loaded with picric-acid mixtures explode, and which on the European battlefields have earned for them the name of "Jack Johnsons."

Toluene is a near relative of benzene; it is a liquid slightly less volatile than the latter substance, and is also a by-product of the coke and gas industry. From it we can obtain trinitro-toluene—



This product is also used as a modern high explosive, under the abbreviated name of T.N.T.

Chemistry has made other contributions to the art of war beside those comprised in the coal tar industries and nitrogen fixation. Reference must be made to the use of poison gases which did such dire havoc on the battlefields of France. Started by the Germans with the simple elemen-

tary corrosive gases, chlorine and bromine, the ingenuity of the chemists of all the world was quickly taxed to develop this deadly and inhuman warfare both in offense and defense. Most of the poison gases were not new discoveries, but were organic compounds of variously complex nature already well known to chemistry. The problem was one rather of chemical engineering to devise ways and means of large scale preparation, shipping and loading such dangerous substances without injury to those engaged in their manufacture and handling. The famous so-called mustard gas which produced such terrible suffering was in no way related to mustard but was a coal tar product of a complicated molecular structure. There is a well known group of organic compounds in which the poisonous element arsenic replaces some of the hydrogens in the molecular configurations. These so-called kakodyl and their allied compounds produce gases which are first nauseating and then fatal when inhaled, and these as well as others equally deadly were being secretly developed by chemists everywhere when by good fortune or by design, just as one may prefer to believe, the great war came to its sudden end at the eleventh hour in 1918. Had the war continued for even a brief space longer, the civilized nations, through the prostitution of the wonders of chemistry, would have drenched each other in poisonous gases which would have reached the innocent with the guilty and in very truth have visited the sins of the fathers upon the children. As it was, race suicide, after the destruction of ten million men, was halted just in time.[6]

[6] For the benefit of those who may be interested in the chemistry of the poison gases which were used in quantity during the war the following list with the chemical names and formulæ is appended:

Chlorine. First gas used by the Germans.

Phosgene. Carbonyl Chloride ($COCl_2$). Lung irritant.

Mustard Gas. Dichlordiethyl sulphide $(CH_2ClCH_2)_2S$. Blister Gas.

It is pleasant to turn from the destructive aspects of modern chemistry to the more merciful and constructive purposes designed to meet and defend against the attack of shot and shell and gas. When the Germans first launched their chlorine gas clouds against the British before Mons, there was no defense known. Rags torn from clothing, soaked in the filthiest water immediately obtainable and tied about the men's faces provided but inadequate defense against this new terror. Why the Germans did not march on to Calais following their gas clouds and thus attempt to force an early victory, God alone knows, for history has not told us. For a number of years previous to the outbreak of the war, scientists and engineers had been studying safety in coal mining operations, and gas masks to be used by rescuing parties in mines had already been experimented with. This new menace of war made a sudden call not only for new forms of masks but for new chemical absorbents to be used in them. There were well known absorbents such as soda-lime, which would take care of chlorine and bromine, but which were quite useless against the various new organic poisons which the German chemists were constantly sending forward. It had long been known that charcoal powder had the power to some extent of absorbing bad odors from vitiated air. Now bad odors are usually due to large complex organic molecules as distinguished from the smaller diatomic molecules of nitrogen and oxygen, of which pure air is composed. Charcoal is a substance so finely porous that even when it is powdered the tiny particles are themselves full of submicroscopic pores just as a microscopic

Chlorpicrin Tear Gas. Nitro trichloro-methane (CCl_3NO_2). Vomiting Gas.

Sneeze Gas. Diphenyl chlorarsine $(C_6H_5)_2$ AsCl. Smoke Gas.

The latter substance is not a true gas but is used as a smoke designed to penetrate the protective gas-mask.

sponge would be. This fine open structure has been scientifically referred to as a mycellian web. It seems that whereas the small molecules of the simple gases can move readily in and out and through this web, the larger molecules of odoriferous gases become entangled and caught. These molecules, of course, do not come to rest, for molecules are never quiet except at the absolute zero temperature, but they may be thought of roughly as like a multitude of angry spinning buzzing flies caught in a tangle of spiders' webs.

There is a far-reaching literature on the absorptive power of various charcoals for gases which goes back to the early days of Priestley. It is curious that this extraordinary property found little or no use in the service of mankind until the emergency of the German gas attack in 1914. In 1863 M. A. Hunter, an English scientist, had already published experiments in the *Philosophical Magazine* which showed that the charcoals made from hard woods such as ebony and from nut-shells greatly exceeded in absorptive power that of ordinary charcoals, but in spite of the extended literature, the subject attracted little attention prior to the war. Those who are interested in this subject should also look up a paper by Dr. R. Augus Smith printed in the *Proceedings of the Royal Society* in 1863 on some important experiments on the absorption of gases by charcoal; also a paper of de Saussure communicated to the Geneva Society as far back as 1812.

Immediately when the call came to the chemists to save the men on the battle front from the deadly gases, they bethought them of this curious property of charcoal, which was at once mixed with the soda-lime and other absorbent chemicals placed in the breathing tanks of the gas-masks. Experiments soon confirmed the claims of investigators that the denser charcoal made from cocoanut shells and peach

stones was finer-poured than ordinary wood charcoals, and therefore a much more effective absorbent. We all remember the baskets on the street corners of our great cities during the war, with signs upon them asking the public to deposit peach stones and nut shells for the protection of our soldiers. There is a sequel to this story, however, which is even more interesting, and one that we may justly be proud of as a distinct contribution of American chemistry. It was found that shell charcoal that was heated in a muffle to a high temperature in the presence of superheated steam was activated so that it would absorb many times the volume of heavy gases that the untreated charcoal could hold. This activated shell charcoal will take up about its own weight of odoriferous gases and vapors, and so vigorous is the action that when the stream of gas is rapid the charcoal actually becomes so hot from the molecular struggle that the hand cannot be held upon a vessel in which the absorption is rapidly taking place. It seems almost as though the activated charcoal possessed an attractive force for heavy gas molecules, just as a magnet will pick up iron filings and hold onto them. But this is not the case. The explanation is that the gas molecules in their rapid motions in every direction impinge upon and bombard the charcoal particles, whereupon the heavy, large ones are entangled while the lighter and smaller ones are unimpeded and are free to move on. To use a very homely and rather rough illustration, we have only to think of a poultry brooding coop in which the little chicks are free to run in and out and away, while the nervous and excited mother birds are forced to confine their motions within the meshes which hold them imprisoned.

Furnished with a gas mask containing activated charcoal, it is now perfectly safe to enter an atmosphere laden

with the most poisonous gases known to chemistry or that chemists will ever be able to devise. It is probably obvious to even a layman in chemistry that this miraculous property of charcoal developed under the exigency of hideous war will fill many a useful purpose in the peaceful arts. The author is glad to be able to report that a number of well-known chemists have been working in this field of investigation since 1917 and are already adapting the principle to the saving and recovery of valuable gases and vapors that result from certain large scale manufacturing operations and which heretofore it has not paid, by any previously known process, to collect and recover from the air with which they are mixed.

We have had space to touch only some of the high spots in the relation of what chemistry has done for war—both in offense and defense—but we cannot leave the subject until we pay some attention to the contributions of chemists to the alleviation of suffering and the saving of life. Gun shot and shell wounds on the battlefield, which would not of themselves result in death, by infection produce tetanus and gangrene with terribly fatal results. Previous to the great war the most efficacious first aid treatment of deep wounds was to pour into them tincture of iodine. This was a heroic and most painful proceeding, to say the least, and was accompanied by undesirable surgical complications. It is interesting to note in passing that the Germans began an abnormally large importation of iodine, which is extracted from seaweed, months before the assassination at Sarajevo, which is generally supposed to have been the starting point of the war. In the early days after the outbreak of hostilities, the famous Dr. Carrell introduced his method of irrigating deep wounds with a watery solution of hypochlorite, which had the effect of gradually giving off nascent instead of iodine

(newborn) atoms of chlorine and molecules of hyperchlorous acid which kept the wound surfaces aseptic without burning the torn tissues as iodine had done. This was a great step forward, but it was not first aid and could only be applied to those cases which survived to reach base hospitals where irrigating apparatus was available. To pour a watery solution into wounds is not efficacious, as the action of the antiseptic must be gradual and continuous. If a substance could be found, that would be soluble in an oily medium and would do all that the watery solution of hypochlorite did, it would be retained by the wound. Now we have already learned in a previous chapter that the derivative of coal tar known as toluene, when treated with nitric acid forms the great staple high explosive, trinitrotoluene, T.N.T. With nitrated toluene wounds are inflicted, and now the chemical wonder grows, for from practically the same starting point we proceed to cure them. Nitrated toluene, properly treated with a so-called reducing agent, will substitute hydrogen for the oxygen fixed to the nitrogen in the molecule. This leads to an organic molecule known as an amine. If this is treated with chlorine in a special manner, we get dichloramine T which is soluble in antiseptic oils such as chlorinated eucalyptus or paraffin. With this material we are told that Dr. Dakin and his associates have not only revolutionized the treatment of deep wounds but have opened up a new field in the asepsis of dental, nasal, and bronchial complications.

So much for some of the important things chemistry has done for man under the stimulation of war. We must now give attention to some of the aspects of chemical research which the recent great war has helped to bring more prominently before us.

We have already referred to the food problems of the future as affected by chemistry through the fixation of nitrogen. The three great staple plant foods are fixed nitrogen, phosphates, and potash. This is revealed by the fact that the ashes or inorganic portion of nearly all plants are made up principally of these constituents together with a little lime, silica and traces of other scattering elements. This country is rich in phosphate rock which is found in great quantity in Florida, the Carolinas, and Tennessee. Treated with sulphuric acid, this phosphate becomes so-called super-phosphate, the soluble form which is required by intensive agriculture. Putting fertilizer on the soil is very similar to putting money in the bank, we may place it as an active or checking deposit and draw against our account for current use, or we may make an interest bearing time deposit for the future. This principle is not sufficiently recognized in this country where the tendency is to use always the more immediately soluble form of fertilizers, which is comparable to the current account at the bank, which instead of saving against the rainy day permits the rainy day to literally wash away a goodly portion of our investment in the too soluble plant foods we have employed. Even our State and Federal laws which are supposed to be drawn up under the scientific supervision of Departments of Agriculture, have subscribed to this tendency by making it difficult if not impossible for any person or company to sell fertilizers that are not immediately and readily soluble in water or soil solutions. This fact applies to the potash situation as well as to the phosphate, and in a much more interesting way on account of its bearing on the international situation. Just as the world's supply of fixed nitrogen exists in one locality in Chile, South America, the world's supply of soluble potash salts up to the end of the war was

exclusively held by Germany in the enormous crude potash deposits of Stassfurt and Alsace. During the war the rest of the world was much put to it to scratch up enough of this necessary alkali from all possible sources, while the price at once rose from about $30 to over $400 per ton on the unit basis used in marketing potashes. Our own necessary supplies come from the fractional crystallization of salt brines from wells and lakes in the Middle and Far West, from leached hardwood ashes, from the giant seaweeds or kelp of the Pacific coast, and in some small quantity from the New Jersey green sands. These sudden substitutions were not accomplished without much upsetting of the accustomed run of things in agriculture and industry. Potash extracted from some of the western brines was found to contain borax which killed many thousands of dollars worth of potatoes in the great potato growing district of Aroostook County, Maine, during 1918-19. Many of the brine potashes contained bromides so that the potassium chlorate made from them, a salt absolutely necessary to the manufacture of matches and percussion caps in ammunition, was found to contain bromate and did not do its work as it should have done, at a very serious cost in money and efficiency, until our chemists had time to study and overcome these perplexing problems.

America still has no adequate supply of soluble potash for use either in peace or war. The granitic rocks which form the geological back-bone of our eastern and western plateaus are made up principally of the three minerals, quartz (silica), feldspar, and mica. The two latter are potash bearing minerals, although naturally the potash is locked up in a molecule which is almost insoluble in water. A granite mountain in New Hampshire or in Wyoming may average as high as 5 per cent potash. In one ton, or about a

wagonload, of this rock there is one hundred pounds of potash. In a million tons out of the mountain side there are a hundred million pounds of potash. In the mountains from Maine to the Carolinas and from Wyoming to the Gulfs there are many great dykes of potash feldspar and the allied minerals leucocite and cerescite, which are richer in potash than the matrix granite. Let us see what Nature has been doing with these materials for her uses since the beginning of organic life on the planet. We have said that the potash is locked up in an insoluble form in these rocks, but this is only comparatively true. Under the action of water and erosion, the mountains are gradually disintegrated and the detritus is washed down into the valleys. Then gradually, by the chemical actions of Nature, the potash is liberated and seized upon by the growing plant life to be stored up in the organic cells. The residue left after this natural extraction forms the clay beds with which we are familiar. We can now understand why Aroostook County, Maine, in spite of its most northern location, with its late spring and early winter, was for many years the richest agricultural county in the United States, for it is nothing but a pocket surrounded by granite hills. It is only after many years of intensive potato growing that this valley has been obliged to import soluble potash from Germany or the western brines, for the potato shares with tobacco and most succulent crops the characteristic of being a voracious potash feeder.

Here, then, is a problem for the United States to work out in the future. It cannot be that this vast store house of potash is to be left forever unused by man. The chemists have been forehanded with this problem and already it is worked out on the semi-commercial stage of operation and is only waiting for timid capital to commercialize.

Some years ago a considerable number of tons of feldspar from Maryland and Virginia were treated by a process devised by the author and Dr. G. W. Coggeshall, and distributed to a number of the State Agricultural Experiment Stations, as well as the U. S. Department of Agriculture. The Director of the Rhode Island Station[7] has recently published a paper showing that after four years of experiment the so-called American Rock Potash produced higher crop yields than corresponding plots treated with equivalent quantities of the soluble German potash salts. It has been our boast that we Americans are a forward and an enterprizing people and in purely mechanical matters, as represented in the manufacture of automobiles by the thousands a day, this is true. But American capital has never yet properly supported the chemists of America, and much of all that has been done in this country in these lines previous to 1917 was done by Germans; whether they possessed naturalization papers or not is quite beside the mark.

[7] The Manurial Value of a Modification of Orthoclase-Bearing Rock where only Potassium was Deficient, by Burt L. Hartwell. *Jour. Amer. Soc. of Agronomy,* Vol. II, No. 8, 1919, page 327.

CHAPTER V

CHEMISTRY AND THE FUTURE

OUR present topic is chemistry and the future. And what is more modern and holds more mysterious promise for the future than the phenomena connected with the discovery of radium and radio-activity? First let us trace some of the steps that led to the discovery of the magical element radium, and then we will look into the subject of its properties and its promise for the future.

The discovery of radium and its properties really traces back indirectly to the year 1785 when Henry Cavendish was sparking air in an inverted glass U-tube, as related in a previous chapter. Cavendish's irreducible residuum was a century later discovered by Raleigh and Ramsay to be the atmospheric inert gas argon,[1] and this quickly led on to the discovery of helium, the sun element, as we shall presently relate when we come to this story, for helium is born of the explosion of radium atoms. In the meantime, Sir William Crookes was studying radiant matter through the medium of highly evacuated glass tubes and globes into which platinum electrodes were fused so that static electric charges could be made to pass through high vacuo. While experimenting with Crookes tubes, Roentgen, a German physicist, in 1895, accidentally discovered the Roentgen or X-rays. These rays, it soon appeared, emanated from the

[1] See page 42.

glass walls of the evacuated globe as a result of their bombardment by the cathode rays which streamed off the electrode. These mysterious X-rays find ordinary matter as transparent as is glass to light rays, and only the heavy metals and minerals are practically opaque to them. The fact that flesh and blood are more transparent to them than the bony and sinuous structure of the body has been of incalculable value to surgery, although the author remembers the contempt with which some eminent surgeons greeted the promise of Roentgen's discovery in 1895.

Another extraordinary phenomenon of the X-rays, which led to the discovery of radium, was their power to make certain crystalline substances, such as the beautiful platinocyanide of barium or one of the natural sulphides of zinc, glow with a greenish light whenever X-rays impinged upon them. This phenomenon led Henri Becquerel, a French physicist, to examine the radiations from all minerals which were known to be phosphorescent, in the expectation that the faintly luminous rays which these bodies emit might contain penetrating rays similar to or allied with Roentgen's X-rays.

It should be explained that when we say that a mineral or salt or any other body is phosphorescent, we do not mean that it necessarily contains the element phosphorus in any form, but merely that it possesses the power of glowing in the dark, either spontaneously or as the result of friction or agitation. As a matter of fact, phosphorus itself glows in the dark, due to its slow burning or oxidation which really phosphorescent bodies never do. Among the many phosphorescent substances which came under Becquerel's observation were the salts of the heavy element uranium. The method of experimentation was to seal up photographic plates in black paper and then lay the substance under in-

vestigation on top of the protected plate and by subsequent development in the dark room, determine whether any penetrating rays had affected the sensitive film. Some substances, as for example a form of calcium sulphide, will give off phosphorescent light after exposure to sunlight, but the effect is evanescent and the luminescence soon dies out. None of these substances had any effect on Becquerel's plates but when he tried uranium compounds he was surprised to find that they invariably produced an intense fogging of the plate and that this phenomenon was quite independent of whether or not the compound had previously been exposed to sunlight or whether or not it gave off rays visible in the dark. Here was an entirely new order of phenomena for which there was neither precedent nor explanation.

The next discovery that Becquerel made was that the rays emitted by his uranium compounds would discharge the electrified gold-foil leaves of an electroscope when brought near them. This could mean but one thing, that the new radiation, whatever it was, had the power of rendering the air surrounding the leaves of gold, an electrical conductor. In its simplest form, an electroscope is an instrument that any clever schoolboy can easily make in a few minutes. Two little leaves of gilder's foil are attached, hanging side by side, to the bottom of a brass rod which passes through a cork into a bottle or glass tube. If a bit of vulcanite or amber is rubbed on the coat sleeve and touched for an instant to the top of the brass rod protruding from the bottle, the charge of static electricity will at once be transmitted to the hanging gold leaves and, since bodies that carry charges of the same sign repel each other, the little pendulous gold leaves open up like an inverted letter V. The leaves will remain in this position for a long period

when the air in the bottle is dry, but, as we now know, if a radio-active body approaches within a measured distance of the leaves, they will drift together under the pull of gravity with a speed or rapidity proportional to the degree of radio-activity of the substance under examination. If a little graduated scale and focusing lens is attached to the instrument, the observations may be made quantitative. Armed with just such a simple instrument, Madame Curie, a Polish woman, and her husband, Professor Curie of the Sorbonne in Paris, proceeded to explore the radio-activity of a great number of minerals. Following up Becquerel's observations, it was soon found that the electrical conductivity of the air induced by the rays from a uranium compound varies directly with the amount of this element present in the mineral. From this point on discovery followed discovery with such rapidity that science held its breath with astonishment and the ultra-conservatives who always behave as though any new knowledge or generalization was an insult to past learning were kept busy denying anything and everything and becoming more and more, metaphorically speaking, red in the face as announcement after announcement came from the Curie laboratory.

Pitchblende is the name of an ore of uranium which is found in quantity at Joachimsthal in Bohemia, and specimens of this mineral proved to be 2½ times more radio-active than uranium itself. There was but one explanation and this was that associated with uranium and contained in its ores there was an unknown radio-active element. Madame Curie set herself the task of working out this problem.

Neither time nor space will permit us to trace the chemical processes followed in this research, but in the end not only was radium isolated and studied but several other radio-

active elements were recognized and described. As the result of Madame Curie's investigations and the subsequent classic researches of Professor Rutherford, we now know that the amount of radium present in a mineral is uniformly about 3.4 parts in every 10,000,000 parts of uranium present. Since uranium ores are of rare occurrence and where found contain only limited percentages of uranium, we can easily understand how scarce and costly this wonderful element must probably remain. And perhaps its enforced rarity is a fortunate matter, for on account of the atomic energies that it lets loose, an ounce of radium accumulated in one mass would be a most dangerous and destructive material. The radium atom is now known to be continually breaking down in a series of atomic explosions which in common with all explosions liberates very sudden energy. So small is the mass of an atom, however, that Rutherford has calculated that one-half of a given mass of radium is destroyed in about 1300 years.

We have said destroyed, but the atoms of radium explode into several products, one of which is the light gas helium, so that we stand face to face with the ancient dream of the transmutation of the elements. Perhaps it is reserved for science in the future to learn how to unlock the atomic forces in elements more abundant than radium. If that day comes, and it is by no means impossible, humanity will face an entirely different order of life and labor. This truth of this statement is brought home to us when we learn that J. J. Thomson, the eminent mathematical physicist, has calculated that if the energy in the atoms of the lightest known element, hydrogen, could be liberated, one gram (15⅓ grains) would suffice to lift one million tons to a height of more than three hundred feet.

We must observe, however, that radio-active energy so

far has been found associated mainly with the atoms of high atomic weight, as though in the evolution or gradual creation of the chemical elements Nature had overreached herself to the confines of stability, even as in a lesser way a child may do with a house of blocks or cards or sand. One story may be stable and stand, but as the structure grows, it becomes more and more precarious until finally it falls apart into its constituent units or groups of units.

A book might be written, as many books have been written, on the mechanism of the radium atoms and the astounding phenomena which attend their disintegration into constituent parts, and of the Alpha, Beta and Gamma rays which are given off as the atomic explosions take place and of the extraordinary and marvellous radium emanation that, like the ghost or astral body of radium itself, confers for a time the property of radio-activity on other bodies with which it comes in contact.[2] Interesting as all this is, the limits of space prevent following in detail all that has already been discovered. We have at least taken a glimpse into one great field of scientific promise for the future of the human race.

It has been computed that in an ordinary candle flame there must be at the very least some two hundred thousand billion molecules at any given instant, and that each one of these molecules in each second of time makes at least fourteen thousand collisions with other molecules. It takes more imagination than most of us possess to make a mental picture of what is going on in a tiny flame like this, but we realize that the results of this molecular activity are easily measured in light, heat and chemical activity. If we now

[2] According to Professor Tilden, Sir William Crookes possesses a diamond that has turned olive green by prolonged contact with radium rays and is in itself become radio active.

transfer our attention to the sun, the source of all the energy that makes life possible, our minds reel in attempting to picture the atomic and molecular activities and the results which they produce. We are all familiar with the visible spectrum of sunlight which we see in the rainbow and in a glass prism. With the spectroscope we can analyze the incandescent vapors which surround the numerous suns in the firmament and can see that they contain many of the well known terrestrial elements and only a few if any that are not now known on earth. But at both the red and the violet end of the spectrum there are rays invisible to our eyes, which produce very decided and wonderful chemical effects, and it is reserved for the chemists and physicists of the future to explore this wonderful and fascinating field. Already the ultraviolet rays are being put in harness to produce practical results in various processes of industrial chemistry.

While we are on the subject of radiant energy from the sun, we may be permitted, although it is not distinctively a chemical problem, to touch upon the latest scientific excitement with respect to the nature of light. As he has been so often asked by friends to explain the new scientific theory of light, the writer is glad to set forth his own understanding of much that has been very recently published on this subject, although it must be confessed that there is much about this problem in astronomical physics that is quite beyond the ordinarily well educated person. To begin with, we may find it helpful to quote a paragraph from Geoffrey Martin,[3] written before Einstein's theory of light challenged the Newtonian conception of matter. This author says in 1911:

[3] *Triumphs and Wonders of Modern Chemistry*, page 53.

We still have to face the problem of the continual radiation of heat and light into space. This has always seemed a great waste to many scientists who could not bring themselves to believe that it was really lost. This objection has been well voiced by Newton himself. "What," says he, "becomes of the great flood of heat and light which the stars radiate into empty space with a velocity of one hundred and eighty thousand miles a second?" Only a very small fraction of this can be received by the planets or by other stars, because these are mere points compared with their distance from us *and from each other.*[4] Taking the teachings of our science just as *it has stood* we should say that all this *light* continued to move on *in straight lines* through infinite space forever. In a few thousand years it *would reach* the confines of our great universe. But we know of no reason why it should stop here. During the hundreds of millions of years since all our stars began to shine, has the first ray of light and heat kept on through space at the rate of a hundred and eighty thousand miles a second and will it continue to go on for ages to come? If so, think of its distance now and *what its final goal will be?* Rather say that the problem what becomes of *a ray of light* is as yet unsolved.

Now we have recently learned that Einstein, a Swiss astronomical physicist, had been led to predict that light waves or rays do not travel in straight Euclidian lines through space, but would be found to have mass and would therefore be pulled or deflected by gravity as they passed within the sphere of influence of the heavenly bodies. Einstein even went so far as to predict the deflection in seconds of arc that the light rays would suffer as the result of the pull of gravity. The recent total eclipse of the sun permitted accurate observations of the apparent positions of a group of stars that could be photographed during the

[4] Italics are the writer's.

darkness of the eclipse and compared with pictures taken at night at a time when the sun was not in a position to influence their rays. As a matter of fact, the cameras showed the stars apparently were not just where they should have been according to the Newtonian theory of the straight lines of light. They did, however, closely approximate to the apparent positions they would occupy if Einstein's deductions were correct.

Of course, there are numbers of scientists who are kept busy inventing other theories and denying the validity of the evidence, just as numerous others explained away the prediction of the existence of the planet Neptune before it was ever seen, or the prediction of unknown chemical elements by Mendeleef previous to their actual discovery.

But let us see what this theory of Einstein's really means in such simple language as we who are not astronomical physicists can understand. At all events this is what the writer makes out of it. In a purely Euclidian sense we can define a straight line as the shortest distance between two points, and we can try to imagine these points at infinite distances apart. We can then state that two parallel lines will never meet, in spite of the fact that in a mathematical sense parallel lines always do meet at infinity. It is all very well to juggle with these mathematical expressions, but manifestly no one can either draw or imagine a straight line infinitely long. In the Newtonian sense, however, rays of light travel in straight lines; they are actually existent things and not abstractions, and our imaginations can accompany them on their travels. They mark or have marked the only straight lines of, to us, practically infinite length we have known or can imagine. Now we are told that they are subject to the pull of gravity, and if this is true, even to the

UNIVERSITY OF CALIFORNIA
DEPARTMENT OF CIVIL ENGINEERING
BERKELEY, CALIFORNIA

slightest extent, they can no more escape from the confines of what we choose to call a material universe under the universal drag of gravity than can a stray atom of hydrogen afloat in interstellar space so escape, or a comet follow its hyperbolic orbit to so-called infinity. With these thoughts in our mind, perhaps we can understand the scientific jargon that tells us that in the Einsteinian sense, as opposed to the Newtonian or Euclidian sense, there are no such things as straight lines, which become merely curves of great magnitude, that straight lines must, like homing pigeons, come back some day to their beginnings, and that actually as well as philosophically we must set a confine somehow or somewhere to the, to us, limitless universe.

Now! What, it may be remarked, has all this to do with chemistry? In reply we can only plead that we are now dealing with the chemistry of the future and chemistry attempts to study, elucidate, and explain the nature of matter. Matter is ever subject to the action of gravity and in its very nature and essence ever must be. Remove gravity in any universal sense, and, ipso facto, all material universes drop to pieces and cease to have being. It will be the province of chemistry in the future to explain matter, and if light is in truth subject to gravity, it is a form or manifestation of matter and falls within the realm of the chemist.

One word in conclusion before we leave these astro-physical discussions and return to those which are more of the earth earthy. It has become the habit of human speech to degrade the word matter. A materialist has come to mean a small-minded man who denies the spiritual conceptions of life and the existence of the God head. A very prominent and growing religious sect has founded its church on the denial of matter or the assertion of its unworthwhileness. There is no sensation in matter, we are told; in this mar-

velous focus of corruscating living energies, without which in very fact no spiritual perception of the great cosmic plan could have ever been made manifest. We sense and perceive matter only through the great law of gravity which moves and controls the stars in their courses. Indeed gravity and matter must be the very warp and woof from the loom on which the Creator weaves the everlasting web of life and love and destiny.[5]

[5] Those who are interested in these speculations and explanations of the nature of matter will derive instruction and entertainment by reading Fournier d'Albe's popular works on the *Electron Theory* and *Two New Worlds*—Longman Green & Co.

CHAPTER VI

SOME MODERN ASPECTS OF CHEMISTRY

WE may venture to predict that if the chemist is ever able to shed any light on the real nature of matter, he will approach it from the standpoint of the atom and the molecule rather than from that of the star rays and the suns. As Sir William Tilden reminds us, "Human existence hangs between two great worlds, the infinitely great and the infinitely little, and into both the chemist can penetrate."

Although the earth in her annual orbit sweeps out a circle of 180 million miles, the ordinary observer, so vast is the stage, sees little or no change in the celestial scenery represented by the relative position of the visible stars. And at the other end of the scale it is calculated with considerable mathematical precision that the electrons of which all the atoms of matter are now believed to be constituted have a mass of only about 1/1800th part of that of a hydrogen atom. It is said that the absolute mass of an electron is 6×10^{-28} gram and its radius 10^{-14} of a millimeter which in itself is less than 1/16 of an inch. Such dimensions lie far beyond the limits of human imagination, but they actually exist, nonetheless. We can, however, with the modern ultramicroscope actually visualize such extremely small particles of matter that they may be considered as beginning to approximate if not the size of some of the larger molecules

themselves, at least they begin to partake of the same order of magnitudes.

This introduces to us the subject of the so-called colloids and dispersoids, in the study of which the chemistry of the future will find a most important and wonderfully interesting field for research.

Suppose we take a cubic inch of stone and by cross cutting cleave it into four smaller cubes of ½ inch face. Now assume that we can repeat this process more or less indefinitely and thus produce first sixteen cubes of ¼ inch dimension, then sixty-four of ⅛ inch and so on. By the time we have concluded the seventh operation, our units measure 1/64 inch, about the size of grains of sand on the seashore, and there are some sixteen thousand of them. They might now be held in a heaping tablespoonful. Now just let us imagine that we could carry on this comminution through seven more cleavage cycles. We would then have unit cubes of about 1/8000th inch and some two hundred and sixty-eight million of them. As a matter of fact, by grinding our material in an agate mortar we can carry our fineness of particle on down to such a degree that if we can by any method separate one particle from its fellows it will require the most powerful microscope to resolve it so that it will be individually perceptible. Now this can be done by shaking up a small weighed quantity of the powder in a liquid to form a suspension or emulsion and examining a drop of this under the microscope. Ordinary microscopes may give a magnification up to 3000 diameters under the most favorable circumstances, and thus render visible objects which have a size of about one ten-thousandth of a millimeter across. The ultramicroscope, a very modern instrument, will resolve particles ten times smaller than this. Now the question arises, how small is it possible to grind

our powder by keeping at it indefinitely? That there is a mechanical limit of possibility in this direction, is at once apparent, for otherwise we should finally arrive at the condition of free molecules of our substance, and, as molecules are invisible to even the plus ultra of microscopes, we should find ourselves rubbing our powder into invisibility, in very truth a "reducto ad absurdam." We can, however, by special methods study fine particles down to the limits of the resolution of our ultramicroscopes, and an entirely new field of physics and chemistry opens up before us.

In 1827, Dr. Robert Brown, an English botanist, observed that the smallest particles in suspension in water that can be seen with an ordinary microscope are in a state of continual movement, apparently buzzing about in a manner that suggests a swarm of tiny angry insects. This Brownian movement has no relation to the kind of matter under examination but only to the size of particle, which must not exceed three one-thousandths of a millimeter (or 3 μ as we express it) in diameter. The easiest way to prepare these so-called dispersoids for study is to dissolve a little resin in alcohol and then pour this solution into water in which the resin is insoluble, thereby producing a milky emulsion. As a matter of fact, milk is just such an emulsion of tiny fat and casein globules in water. Such emulsions pass through filters unchanged and can only be broken down by chemical or better by electro-chemical means, for it now appears that particles of such tiny magnitude in liquid suspension accumulate upon their surfaces like charges of electricity, due probably to the friction of the rapidly moving molecules of the suspending liquid. Now we all know that light bodies carrying electric charges repel each other, so that our moving particles will not get together and flocculate or coagulate until we do something to electrically discharge them, a

very important matter in the clarification and filtration of many industrial liquids, as well as the modern ore flotation processes. It is now believed by students of this fascinating subject that the Brownian movement of dispersoid particles in suspension is not due to any inherent motive power in the particles themselves but that they are merely being kicked about by the rapidly moving molecules of the surrounding liquid, among which they hang suspended. From this we may infer that though the particles themselves consist of groups of molecules we have approached an order of mass magnitudes not far removed from that of molecules themselves.

So far we have been considering that phase of so-called colloidal chemistry which has to do with ultimately fine particles. In 1849 Thomas Graham, Professor of Chemistry at University College, London, and Master of the British Mint,[1] first concerned himself with the diffusion of dissolved substances. Graham first called attention to those glue-like substances which he called colloids, which while not truly soluble in water disperse into it. Soluble crystalloids like salt and sugar disappear into water in the form of free molecules which, as we have learned, no microscope is powerful enough to resolve, while colloids disperse as groups of molecules. If we put a solution containing both crystalloids and colloids into a vessel the bottom of which is formed of a parchment membrane, and partly immerse this vessel in a larger one containing water, the crystalloid molecules will migrate freely through the pores in the membrane, but the colloid groups are too large and are stopped as by a screen. Chemists call this method of separation

[1] The author cannot refrain from inquiring why our own Directorship of the Mint, with its large annual stipend, should nearly always fall to a political henchman of the President, usually a man to whom the mysteries of chemistry and metallurgy are as Choctaw and Sanscrit.

dialysis, but it is interesting to us all because this one fact of nature makes organic cell growth possible. If in our membraned dialyzer we place a solution of sugar and immerse this in water, the water molecules can pass through but the sugar cannot. The consequence is that owing to the laws of diffusion and surface tension, a pressure is set up. The water molecules diffuse through the membrane, acting as though they were attempting to bring the sugar solution to a condition of infinite dilution. This diffusion pressure is known as osmosis. Osmotic pressures rise to very great magnitudes indeed and are only limited by the strength of the semi-permeable membranes which support them.[2] It is this phenomenon which explains the rise of sap in the tallest trees, operating against gravity. It also explains the swelling and growth of organic cells, all of which are surrounded with membranes of a more or less permeable nature.[3] A hen's egg which is only a very large cell has such a membrane just underneath its calcareous shell. By blowing out the contents of an egg through a hole bored in one end and substituting a sugar solution in its place, a very good illustration of osmotic pressure can be made. It is necessary first to carefully cement a glass tube over the hole bored in the shell and then dissolve off a bit of the calcareous shell at the opposite end with dilute acid. If we immerse this manufactured osmotic cell in colored water, we will soon see a column of liquid rising against gravity in the tube just as sap rises in the tubulars of a growing plant. It was Pfeffer, a professor of botany at Bale, who

[2] Recently, with improved apparatus, osmotic pressures have been recorded as high as 100 atmospheres or 1,500 lbs. to the square inch.

[3] Professor Adrian Brown has recently shown that the barley grain is covered with a membrane which is active even after it has been boiled, thus proving that the selective action is physical and is not a physiological action of living matter.

first observed and began to measure osmotic pressures about forty years ago, but it remained for Van't Hoff, the famous Dutch scientist, in 1887, to interpret Pfeffer's results and link them up to one of the greatest scientific generalizations of all times. Van't Hoff first called attention to a complete parallelism between osmotic pressures and the laws which govern gas pressures. In other words, the sugar molecules in solution exert pressure similar and equal to the pressure of gas in an enclosed vessel, and tend to obey Boyle's, Gay-Lussac's, and Avogadro's laws of gas pressures and volumes. The boundary of a liquid is governed by what is known as surface tension which makes small quantities of detached liquids behave as though they were enclosed in an elastic skin which tends to compress it within the smallest possible space. As liquids are incompressible in all directions, they thus, when in detached masses, always appear as spheroid drops. Within this bounding surface tension the sugar and water exert osmotic pressure.

But now Van't Hoff discovered an entirely new and marvelous principle in chemistry. It was already known that solutions of sugar and similar water soluble organic substances do not conduct electricity, while common salt and other soluble inorganic salts, acids and alkalies are generally good conductors, but there was no explanation of this fact. It was now found that while sugar and other organic molecules obeyed the parallelism with the gas law of Avogadro [4] that equal molecular weights dissolved in equal volumes of the same solvent exert the same osmotic pressure, inorganic substances exert in all cases pressures much higher than this, and in many cases of dilute solution just twice as

[4] Avogadro's law is that equal volumes of all gases at the same temperature and pressure contain the same number of molecules and exert the same pressure. cf. Chapter I, p. 24.

high as the theory calls for. Here was a fact that required an explanation, and the explanation was forthcoming in Van't Hoff's *Theory of Solutions*. This theory which although it has been much controverted has stood the test of time and experiment, recites: that all conductors of electricity in solution are more or less dissociated, depending on the dilution, into ions which are simply the atoms or groups of atoms carrying equal and opposite charges of electricity. If we dissolve a molecular weight, measured in grams (a gram molecule), of sugar in a given quantity of water we get a normal osmotic pressure. If we dissolve a gram-molecule of salt in the same quantity of water, we get an osmotic pressure due to the summation of the chlorine and sodium ions, or twice as much as an undissociated molecule would give. We now write these dissociations as shown in the following reactions:

$$NaCl \rightleftarrows \overset{+}{Na} + \overset{-}{Cl}$$

$$NaNO_3 \rightleftarrows \overset{+}{Na} + \overset{-}{NO_3}$$

It is not necessary here to go into the intricacies of the theory of solutions, but it suffices to say that applied to chemistry as a whole this theory not only explains how electric currents are conducted through some solutions and not through others, but it has also enabled us to understand many of the mysteries of chemistry, which were theretofore inexplicable. In the hands of the chemist of the future, it will undoubtedly lead to much interesting new knowledge.

In treating the subject of the outlook for chemistry in the future, we have so far been dealing mainly with the aspects of pure science. We must now turn our attention to some of the more practical chemical problems of the

future. We have already seen how the waste products of the great coal tar industry are now conserved and turned into useful substances in the by-product coke oven. Almost every industry has its by-products, many of which are still thrown away as useless, to pollute our streams and rivers. This must eventually be changed, and there is a great field open for the chemists of the future. As it is, however, the chemists as usual are far in advance of capital, for it is easier to work out a process than it is to get hard headed practical business men to give it a trial. In the manufacture of newsprint paper alone there is a tremendous drain upon our forest resources. A single Sunday edition of one metropolitan newspaper with its ridiculous colored supplements will use up in one day the equivalent of many acres of spruce and poplar that took years in the growing and which, unless we change our wasteful deforestation will never grow again. The waste sulfite liquors from the paper pulp mills are an invitation to the chemist, and already several useful products can be made from them, including denatured alcohol. Again by cooking sawdust, the by-product of the lumber industry, with dilute sulfuric acid, neutralizing the acid with alkali and fermenting the pulp, ethyl alcohol is made, quite good enough to drink if drinking alcohol had not become taboo, but in any case it can be denatured and used in the arts and industries and eventually perhaps save grain and sugar for other uses.

And, what, we may well inquire, is to be the future of alcohol when the whole world goes dry as it bids fair to do, at least as far as the barter and sale of alcohol as a beverage is concerned? That a considerable body of mankind will ever stop using alcohol as a stimulant seems very doubtful. The simple fact that the juices of all the fruits of the earth

change their starch and sugar into alcohol up to a content of from 15 to 17 per cent by volume by the action of their own natural ferments and enzymes, seems to place the final decision in the hands of a higher tribunal than any man-made legislature. Men can govern what they barter and exchange, but they can no more order a yeast cell or an enzyme to cease its action than King Canute could command the advancing tide. Curiously enough, Christians believe, or to be consistent should believe, that the great Exemplar himself changed water or at least a watery solution into wine that the wedding feast should lack nothing that was customary to the occasion, an act that requires only a deeper insight into the life processes than the ordinary man possesses to accomplish.

But it is not after all as a stimulant that alcohol will play its great rôle in the future history of mankind. Civilization needs power. The nineteenth century worked out its destiny with coal, the twentieth is working toward gasoline and oil. The steam engine started as a coal burner, the internal combustion engine as an oil burner, but what is to come when the coal mines and the oil wells have been gutted? Coal and oil, though abundant, are not inexhaustible, but alcohol can be made while we sleep by the tireless energy of countless billions of microörganisms. Wherever starch and sugar in any form can be made to grow, alcohol can be harvested to feed the engines of the future, as hay and oats were grown to feed the horses of the past. Herein, we may with some degree of confidence predict, lies the future of alcohol in the service of man.

In previous pages we have had occasion to talk much of the liquid hydrocarbon benzene which can itself be used as a motor fuel as a substitute for gasoline, and which is the source of many useful dyes and explosives. If we took a

quantity of it to the arctic regions and presented it to the Esquimaux, they would know it only as a solid unless they warmed it by a fire. For this lambent, very liquid liquid as we know it, turns to ice at ten degrees above the freezing point of water. This is true of many other common substances that we are accustomed to see and handle only in the liquid phase, and would find ourselves quite unfamiliar with in colder ranges of temperatures. Elastic India rubber is as brittle as glass at the temperature of liquid air.

Man can tolerate for a limited period, if he is accustomed to it and takes precautions, a range on the Fahrenheit scale of between 60° and 70° below zero to some 130° to 140° above. In other words, he enjoys, if that term can be properly so employed, an outside range of about 200° F. Let us shift, however, from the silly Fahrenheit scale by which we determine whether we are comfortable or not, to the more rational and scientific centigrade scale.[5] The absolute zero of temperature below which molecular motion and all phenomenal activity ceases has been fixed at 273° below the centigrade zero. Science has explored the region down to as low as only 2.5° C. above the absolute zero. This extraordinary temperature was reached by boiling liquified helium under reduced pressure. Liquid hydrogen boils at 253° below zero, while liquid air boils at—181° C. All of the so-called permanent gases have now been liquified and solidified by intense cold. Only helium has so far resisted solidification. Many people do not understand that before gases can be liquified they must also be under a critical pressure which differs for each particular gas. There is also a critical temperature for each gas, above which no possible pressure will

[5] The Fahrenheit thermometer places the freezing point of water at 32° above zero and the boiling point at 212°. The centigrade graduates these points on the metric system between zero and 100°.

cause it to liquify. When these critical constants are known and the costly apparatus is available, a new world of chemistry and physics is opened up for research.

Many who have given little attention to these modern developments of science may observe that while this may all be very interesting to specialists, phenomena that occur at temperatures far below any that man can experience can have no possible practical bearing or value. In order to see if this is true or not, let us briefly review the interesting story of helium.

When it was learned, soon after its discovery, that the spectroscope could be used to analyze and recognize the composition of incandescent gases, it was at once used to explore the incandescent chromosphere of the sun. The presence of many of our well known terrestrial elements was at once recognized. There was, however, a brilliant yellow line very close to the two sodium lines in the sun's spectrum, which did not correspond with any known element on earth. This line had been mapped by Jansen and Lockyer in 1865 and attributed to a solar element which they named helium. It will be remembered that in an earlier chapter it was told how Raleigh and Ramsay discovered argon in our atmosphere in 1895 by repeating with modern apparatus Cavendish's classic experiment of sparking air and oxygen in an inverted tube over an alkaline liquid, thus causing all of the nitrogen and oxygen to unite as nitric acid and be absorbed by the alkali. Following this wonderful discovery of argon as a new constituent in ordinary atmosphere, the next thing was to endeavor to determine whether or not this element could be found combined in any of the earthy minerals. Since argon has a well defined spectrum, Professor Ramsay and a number of other scientists proceeded to searchingly re-examine the spectra of a

number of minerals and earthy substances, but without avail, for argon refused to reveal its presence. About this time our own Dr. Hillebrand, then chief analytical chemist with the U. S. Geological Survey, had had turned over to him for analysis in the course of his routine work, a sample of the rather rare uranium bearing mineral known as clevite. Dr. Hillebrand noticed that when he boiled this mineral in dilute sulfuric acid, an inert gas was given off, which not having the research equipment at hand to examine the spectrum of, he very naturally presumed was nitrogen. However, although it was a hitherto unknown phenomenon for a mineral to give off an inert, difficultly recognizable gas when heated in a dilute acid, a less expert and conscientious chemist might easily have passed it by and assumed that the gas was merely nitrogen left over from air that was occluded or imprisoned in the pores of the mineral. Dr. Hillebrand did not, however, ignore his observation but published a short note in a chemical journal, describing it but drawing no definite conclusions. Hillebrand's note fell under the eye of Ramsay who jumped to the conclusion that the unusual gas was very possibly argon. The mineralogical museums of London were immediately ransacked for specimens of clevite, Hillebrand's operation repeated, and the gas purified and examined with the spectroscope. To the astonishment of the scientific world, the yellow line of the solar element helium flashed out its wireless message, "I am here."

American science has not made many contributions to the new chemistry of the past quarter century, but it has always seemed to the author that Dr. Hillebrand's announcement was the immediate cause of a long series of very remarkable discoveries. After the isolation and purification of helium, the next thing was to determine its atomic weight which was found to be 4, so that next to hydrogen (1) it is the

lightest of all the gases. While engaged in the study of helium, Ramsay discovered associated with it two other unknown inert gases both of which found a vacant place waitfor them, as had helium itself, in Mendeleeff's periodic arrangement of the elements. These two gases, neon (the stranger)—atomic weight 20—and krypton (hidden)—atomic weight 83—arrange themselves on either side of the equally inert gas argon. For both argon and helium important practical uses have been found, and it is probable that the chemistry of the future will also find something useful for neon and krypton to do.

We have already previously learned how the Crookes tubes led to the discovery of the Roentgen rays and these in turn to Becquerel's discoveries and these to the isolation by Madame Curie of radium and the other radioactive elements, actinium and polonium. We shall now learn how helium linked up to these discoveries. The three elements in Mendeleeff's classification which have the highest atomic weights are radium (224), thorium (232), and uranium (239). It is now known that all these heavy atoms are undergoing a gradual disintegration and that helium is one of their decomposition products. It is possible, if not probable, that in the evolution of the elements Nature attempted even heavier atoms than uranium but that these, owing to their inherent instability, have broken down and that neon and krypton were among their products of disintegration. The theory has been considered that radium is born of the falling down of the heavier uranium and thorium atoms, and that radium in turn, as it throws off helium atoms, gives birth to niton, the radium emanation which is radium (226) minus helium (4) or niton) (222). Those who wish to know more of the recent work of chemistry which bears upon the genesis of the elements in the light of radio-chemistry, will

have no difficulty in finding a rich bibliography of the subject both popular and scientific. There is always a temptation to linger in this fairyland of science, but we must get on to the more practical chemical problems of the future.

We all remember the part that the dirigible balloon played in the war, and that recently an English dirigible has crossed and re-crossed the Atlantic. It would seem that it is now only a question of time before transatlantic aerial passenger and mail transportation will be regularly carried on, provided that the menace due to the extreme inflammability and the explosiveness of the accidental admixture of hydrogen gas with air can be overcome. The answer seems to be helium which is not only uninflammable in itself but when mixed with hydrogen in sufficient quantity makes a perfectly safe, extremely buoyant gas for balloons. During the war somebody discovered that some of our natural gas from the southwestern oil and gas fields contained notable quantities of helium, probably derived from the decomposition of radium contained in subterranean rocks. Since helium is the last gas to resist liquification, we have only to liquify all the other constituents of these natural gases in order to produce pure helium. Several processes for the commercial liquification of air have already been adapted for this purpose, so the future exploitation of helium is only a question of demand and cost of production.

We have been dealing with operations which take place, like the liquification of the permanent gases, at hundreds of degrees below zero. We will now turn our attention to the other end of the thermal scale, where men have been conducting and will continue to conduct chemical reactions at the temperature of the electric arc, thousands of degrees above zero. While heating a mixture of lime and cokedust

in an electric furnace, a number of years ago, presumably with the object of reducing the lime to its metallic base calcium, the experimenter found on cooling the furnace that it contained only a dull gray, limy looking mass. This was considered worthless and was thrown out. It had been raining, and some of the furnace product landed in a pool or puddle of water. To the astonishment of the investigator, contact between this material and water produced a peculiar smelling inflammable organic gas. This was acetylene gas (C_2H_2), and its accidental discovery ultimately established two great industries, first in the manufacture of calcium carbide for the production of acetylene and finally as a step in the fixation of air nitrogen through calcium cyanamid. By heating coke dust and silica or fine sand together with a pinch of salt in the electric furnace, carborundum is made, a wonderful artificial abrasive which has also developed into a great industry. By heating iron ore, coke and silicon to the temperature of the electric arc, we get ferro-silicon. The uses that the metallurgists and electrical engineers have put this material to is another fairy tale of science. By adding a proper proportion of ferro-silicon to a molten heat of open hearth steel, high silicon steel alloys are produced which the designer of electrical machinery has found a most important use for. All electric motors and transformers which supply the powers for the manifold uses of modern civilization are merely variations on Faraday's old principle of winding coils of insulated copper wire around magnetic cores or pole pieces. The efficiency of such apparatus depends largely on the so-called magnetic flux set up in the metallic cores. There are certain eddy currents or what is termed hysteresis set up, which counteract the desired electro-magnetic impulses generated in the machine. By building the cores on armatures of in-

sulated layers or laminæ of high silicon or "electric steel" these effects have been almost entirely overcome.

It must not be supposed that the benefits of a discovery like this accrue only to the manufacturer of electrical machinery. On the contrary, it is the public and humanity generally that reaps the benefit. The weight and hence the cost of machinery per horsepower of energy has been so reduced by this one discovery alone that even the housewife can now afford to carry on by electricity what were once called menial tasks. The saving to the world as a whole by the discovery of high silicon electric steel would aggregate many millions of dollars.

We have been discussing some of the many accomplishments of chemistry at very high temperatures, and doubtless this is a fertile field for the chemists of the future to work in. At a lower range of temperatures much interesting work is going on in which the public is or should be interested. Most of the wheels that turn to do the world's work today are propelled by petroleum or some of its products. Of these probably the most important are the lighter distillation fractions or distillates which we in America class under the unlovely name of gasoline and which in Europe are better named "petrol." Some of the crude oils which gush or are pumped from driven wells contain these light boiling fractions, but the oil from many of the larger and more important fields such as the Mexican contain little or none. This fact has been a matter of interest and study to many chemists who have successfully attempted to do what Nature in many cases failed to do, viz.: provide the light volatile products needed for use in automotive machinery. By distilling or heating in a controlled manner heavy crude oils, the large molecules are "cracked" into smaller and more active ones, and thus gasoline is derived from petroleums

which before the science of chemistry was brought to bear upon them were barren of motor fuel. But even with this, the growing use of the internal combustion engine on land and sea will make a very special demand on the chemists of the future. The author here ventures to predict that the great achievements and excitements that have filled the book of chemical accomplishment during the past half century will be as nothing compared with the triumphs and marvels which are yet to come.

We have now fulfilled the task undertaken when these chapters were begun. At best it has been possible to bring out only the high lights of the general picture, and much is still left indistinct in the shadows. Those who have followed the story must have been impressed with the great contributions that have been made to chemistry by English scientists. From Boyle and Cavendish to Faraday and finally to Perkin, Dewar and Tilden who are still living, the record is a succession of brilliant accomplishment. It will also be noted with pride by all our countrymen that by far the greater part of these triumphs originated in and through the Institution founded in London by the American Benjamin Thompson, soi disant Count Rumford. What more fitting then that we should conclude with words spoken in the lecture room of that Institution by one who though not a chemist is a master of modern thought and expression. H. G. Wells, in a discourse on *The Discovery of the Future*, delivered on January 24, 1902, gives utterance to thoughts which exactly mirror forth those of the present author but which he could not have expressed with such eloquence.

"Our lives and powers are limited, our scope in space and time is limited, and it is not unreasonable that for fundamental beliefs we must go outside the sphere of reason and

set our feet upon faith. Implicit in all such speculations as this, is a very definite and quite arbitrary belief, and that belief is that neither humanity nor in truth any individual human being is living its life in vain. And it is entirely by an act of faith that we must rule out of our forecasts certain possibilities, certain things that one may consider improbable and against the chances, but that no one upon scientific grounds can call impossible. One must admit that it is impossible to show why certain things should not utterly destroy and end the entire human race and story, why night should not presently come down and make all our dreams and efforts vain. It is conceivable, for example, that some great unexpected mass of matter should presently rush upon us out of space, whirl sun and planets aside like dead leaves before the breeze, and collide with and utterly destroy every spark of life upon this earth. So far as positive human knowledge goes, this is a conceivably possible thing. There is nothing in science to show why such a thing should not be. It is conceivable, too, that some pestilence may presently appear, some new disease, that will destroy, not 10 or 15 or 20 per cent of the earth's inhabitants as pestilences have done in the past, but 100 per cent, and so end our race. No one, speaking from scientific grounds alone, can say, "That cannot be." And no one can dispute that some great disease of the atmosphere, some trailing cometary poison, some great emanation of vapor from the interior of the earth, such as Mr. Shiel has made a brilliant use of in his "Purple Cloud," is consistent with every demonstrated fact in the world. There may arise new animals to prey upon us by land and sea, and there may come some drug or a wrecking madness into the minds of men. And finally, there is the reasonable certainty that this sun of ours must some day radiate itself toward extinction; that, at least, must happen; it will grow cooler and cooler, and its planets will rotate ever more sluggishly until some day this earth of ours, tideless and slow moving, will be dead and frozen, and all that has lived upon it will be frozen out and done with. There surely man must end. That of all such nightmares is the most insistently convincing.

And yet one doesn't believe it.

At least I do not. And I do not believe in these things because I have come to believe in certain other things—in the coherency and purpose in the world and in the greatness of human destiny. Worlds may freeze and suns may perish, but there stirs something within us now that can never die again.

Do not misunderstand me when I speak of the greatness of human destiny.

If I may speak quite openly to you, I will confess that, considered as a final product, I do not think very much of myself or (saving your presence) my fellow-creatures. I do not think I could possibly join in the worship of humanity with any gravity or sincerity. Think of it. Think of the positive facts. There are surely moods for all of us when one can feel Swift's amazement that such a being should deal in pride. There are moods when one can join in the laughter of Democritus; and they would come oftener were not the spectacle of human littleness so abundantly shot with pain. But it is not only with pain that the world is shot—it is shot with promise. Small as our vanity and carnality makes us, there has been a day of still smaller things. It is the long ascent of the past that gives the lie to our despair. We know now that all the blood and passion of our life was represented in the carboniferous time by something—something, perhaps, cold-blooded and with a clammy skin, that lurked between air and water, and fled before the giant amphibia of those days.

For all the folly, blindness, and pain of our lives, we have come some way from that. And the distance we have traveled gives us some earnest of the way we have yet to go.

Why should things cease at man? Why should not this rising curve rise yet more steeply and swiftly? There are many things to suggest that we are now in a phase of rapid and unprecedented development. The conditions under which men live are changing with an ever-increasing rapidity, and, so far as our knowledge goes, no sort of creatures have ever lived under changing conditions without undergoing the profoundest changes themselves. In the past century there

was more change in the conditions of human life than there had been in the previous thousand years. A hundred years ago inventors and investigators were rare scattered men, and now invention and inquiry is the work of an organized army. This century will see changes that will dwarf those of the nineteenth century, as those of the nineteenth dwarf those of the eighteenth. One can see no sign anywhere that this rush of change will be over presently, that the positivist dream of a social reconstruction and of a new static culture phase will ever be realized. Human society never has been quite static, and it will presently cease to attempt to be static. Everything seems pointing to the belief that we are entering upon a progress that will go on, with an ever widening and ever more confident stride, forever. The reorganization of society that is going on now beneath the traditional appearance of things is a kinetic reorganization. We are getting into marching order. We have struck our camp forever and we are out upon the roads.

We are in the beginning of the greatest change that humanity has ever undergone. There is no shock, no epoch-making incident—but then there is no shock at a cloudy daybreak. At no point can we say, Here it commences, now; last minute was night and this is morning. But insensibly we are in the day. If we care to look, we can foresee growing knowledge, growing order, and presently a deliberate improvement of the blood and character of the race. And what we can see and imagine gives us a measure and gives us faith for what surpasses the imagination.

It is possible to believe that all the past is but the beginning of a beginning, and that all that is and has been is but the twilight of the dawn. It is possible to believe that all that the human mind has ever accomplished is but the dream before the awakening. We can not see, there is no need for us to see, what this world will be like when the day has fully come. We are creatures of the twilight. But it is out of our race and lineage that minds will spring, that will reach back to us in our littleness to know us better than we know ourselves, and that will reach forward fearlessly to comprehend this future that defeats our eyes. All this world is

heavy with the promise of greater things, and a day will come, one day in the unending succession of days, when beings who are now latent in our thoughts and hidden in our loins, shall stand upon this earth as one stands upon a footstool, and shall laugh and reach out their hands amidst the stars.

APPENDIX

NITROGEN SUPPLIES

COMPILED UNDER THE INSTRUCTION OF THE AUTHOR

By Carleton H. Wright
Lieutenant-Commander, U. S. N.

January 6, 1920

NITROGEN SUPPLIES

Under the stimulus of the demand for nitric acid for use in the manufacture of explosives in the late war such progress was made in the development of processes and the construction of plants for the fixation of the nitrogen of the air that all the leading nations of the world with the single exception of the United States are now practically independent of imports of the nitrates so necessary in times of peace for prosperity, and in times of war for success in battle.

The normal imports into this country total nearly 600,000 tons of sodium nitrate yearly, yet there is now in actual operation for the fixation of the nitrogen of the air just one plant, and it has a maximum production of less than 5,000 tons of nitric acid yearly. This is a privately owned plant, operating on the arc principle, the oldest of all the methods of fixation.

The methods that have been commercially developed in other countries are, in the order of their establishment:

(a) Arc process.
(b) Cyanamid process.
(c) Haber process.
(d) Cyanide process.

THE ARC PROCESS

There are several modifications of this process in use, but in all of them the intense heat of the electric arc is used to

cause the direct combination of the oxygen and nitrogen of the air. The NO formed in the arc is oxidized to NO_2 and the latter is absorbed in water to form weak nitric acid (30-35% HNO_3). The waste heat may be economically employed to increase the concentration of the acid as a further step.

The power requirements for this process are extremely high—at least 2.33 HP per year being required for each ton of acid produced, thus practically prohibiting the adoption of this in the United States, except where unusually cheap power is obtainable. When power can be obtained at a rate of $10.00 per HP-year or less, the manufacture of nitric acid by this process will probably be profitable in *large* plants if a market for the difficultly transportable product is close at hand. So far as is known there is no place in the United States where large amounts of power can be secured at this rate, with the possible exception of the proposed Columbia River power project near The Dalles, Oregon, and this location is not suitable because of the distance from a market for the product. It is possible, however, that in some parts of the country arrangements could be made to obtain power from the off peak load of power supplying companies at such a rate that the manufacture of nitric acid by the arc process will be profitable in this country. In Norway, where the power costs are very low, a large amount of acid is made by this process, but even there the cyanamid process seems to be found the more profitable.

In this country the high installation cost, large power requirements, and improbability of being able to operate at full capacity in time of peace more than equalize the advantages of the process, namely, free raw material and low labor cost.

THE CYANAMID PROCESS

The cyanamid process has been very extensively adopted, plants being in operation in Norway, Germany, Spain, France, Italy, Great Britain, Japan and Canada.

The first step in the cyanamid process is the heating of lime with coke or anthracite coal in an electric furnace to form calcium carbide. The carbide is then finely ground out of contact with air. Next it is heated to redness and nitrogen gas from a liquid air system is passed through. The carbide adds nitrogen to form calcium cyanamid, $CaCN_2$. The cyanamid is then ground to remove any acetylene which may have been formed due to contact of the carbide with moisture.

The cyanamid can be used direct as a fertilizer, or it may be treated with steam in autoclaves to convert the nitrogen to ammonia. The reaction is:

$$CaCN_2 + 3H_2O = 2NH_3 + CaCO_3$$

The advantages of the cyanamid process, viewed from the possibility of its adoption in this country are:

(1) The power requirements are moderate.

(2) The cyanamid finds a ready market as a fertilizer.

(3) The products are readily transportable.

(4) The process is well understood and has passed beyond the initial experimental stage.

The disadvantages of the cyanamid process are:

(1) Large number of operations and plant installations.

(2) Large labor factor.

(3) Undesirable working conditions for labor because of dust and dirt.

(4) Cost of product as ammonia probably higher than

by Haber process. Cost as fertilizer should, however, be lower.

(5) Patents controlled in this country by one company.

THE HABER PROCESS

In the Haber process nitrogen from the air and hydrogen from water or any other available source are directly combined at high temperatures and pressures in the presence of a catalyst to form ammonia. This process was developed in Germany and during the latter part of the war was the principal source of fixed nitrogen there. So far no other country has been able to get a plant into satisfactory operation on a commercial scale. Because of the high temperatures and pressures required, the metallurgical difficulties to be overcome are even greater than those of a strictly chemical nature.

In the Appau plant, one of the largest in Germany operated on the Haber principle, the hydrogen is obtained from the water gas manufactured at the plant. The average percentage composition of the gas, by volume is:

H	49%	CO_2	3%
CO	43%	N	5%

The proportion of nitrogen is increased by mixing in generator gas of the following composition:

H	6%	CO_2	5%
CO	24%	N	63%
CH_4	2%		

The CO in the gas is converted to CO_2, and at the same time a further supply of hydrogen is added by mixing the gas with steam at a temperature of 400-500° C. in the presence of a catalyst which is principally iron oxide with a

very small percentage of other oxides, such as chromium oxide. The reaction is as follows:

$$CO+H_2O=CO_2+H_2+10 \text{ calories.}$$

A slight excess of steam is required, but too great an excess must be avoided to prevent lowering of the temperature.

The CO_2 in the gas is now eliminated by compression at 20 kg. per sq. cm. in contact with water. Any residual CO or CO_2 remaining after this treatment is eliminated by copper formate or copper chloride under a pressure of 200 kg. per sq. cm.

The proportion of nitrogen to hydrogen is kept below 1/3 until just before reaching the ammonia catalyst. Then the required amount is added from a liquid air machine.

Information about the catalysts used has been jealously guarded, but it is known that various substances will bring about the synthesis, among the most satisfactory being pure iron or various of the rare metals. Methane is not a poison for the ammonia catalysts, but practically all the other hydrocarbons are.

The synthesis takes place in autoclaves at a temperature of 400-600° C., and at a pressure of about 200 atmospheres.

At the start of the operation 2% to 6% of oxygen is added and the action begun by an electric spark. The gas after catalysis contains about 6% of ammonia. This ammonia is absorbed by water, a 20% solution being obtained. The unconverted nitrogen and hydrogen are returned to the autoclaves for a repetition of the cycle. The yield is 70% to 90% of the calculated.

The advantages of the Haber process are:

(1) Probably the cheapest method of manufacture of synthetic NH_3.

(2) Ammonia is obtained in a pure condition.

(3) Raw materials are readily available.

(4) Small plants can be erected wherever needed.

The disadvantages are:

(1) Details of the process have not been worked out on a manufacturing scale outside of Germany.

(2) Difficult engineering problems are still to be solved.

(3) The initial costs are high, and the repair and renewal costs large, particularly during the early stages of development.

THE CYANIDE PROCESS

In the cyanide process ground coke, or carbon in any other form, and sodium carbonate are heated to redness in contact with finely divided iron in the presence of pure nitrogen, or even of air, and the formation of sodium cyanide results. Waste nitrogen from sodium carbonate plants or from wood pulp plants can profitably be used with this process. The sodium cyanide produced can be treated with water, and ammonia be produced.

The manufacture of ammonia by this process is too costly to compete with the Haber or the Cyanamid processes as a source of ammonia in time of peace, but as a source of supply of cyanide for use in the gold and silver smelting industries it seems to offer commercial possibilities when favored by local advantages. The process has not been greatly developed abroad.

OXIDATION OF AMMONIA TO NITRIC ACID

Any pure ammonia, no matter how obtained, can be easily oxidized to nitric acid with a yield of 90-95%. The oxidation takes place in autoclaves, the catalyst used being finely divided platinum guaze. A temperature of about 700°

is required for the synthesis. In the Ostwald process as developed abroad this temperature is obtained by preheating the ammonia and air going to the autoclaves, but the process as developed in this country by the General Chemical Company in collaboration with the Bureau of Mines takes advantage of the fact that the action is exothermic, and in this modified process no outside heat is required after the action is once started.

BY PRODUCT AMMONIA

In addition to the ammonia manufactured by synthetic methods, a potential supply is available in all industrial countries in the ammoniacal liquor which is one of the products of the distillation of bituminous coal in gas works or coking ovens. As is well known, this country has been far behind the nations of Europe in the adoption of the byproduct type of oven for the coking of coal. The demand for coal tar products during the war caused some improvement in the situation, but we are still very far from being in a satisfactory condition so far as the recovery of all possible byproducts is concerned.

If the American dye industry becomes established on a firm footing, thus insuring a continued market for the coal tar products, and the present high price of ammonia holds, it is but natural to expect that the highly desirable replacement of the wasteful beehive type of coking oven by the byproduct type will continue. The great room for improvement still remaining is shown by the fact that the present production of byproduct ammonia in this country is now in the neighborhood of 125,000 tons per year, while the possible recovery from coal now coked is approximately 700,000 tons. Increase in the amount of coal coked is to be desired from a viewpoint of national efficiency, and there

seems no reason to doubt that the recovery of byproduct ammonia thus can be made greater than 1,000,000 tons annually. Thus from this one source all the present needs of the country for fixed nitrogen could be supplied, for only an inexpensive purification of byproduct ammonia is required before it can be oxidized to nitric acid.

It should be noted that while all the present needs of the country could be supplied from this source, very slow progress is being made, and long before the possible limit from this source has been reached the demand will have increased beyond the possibility of its being completely satisfied from this source.

THE SYNTHETIC NITROGEN SITUATION IN THE UNITED STATES

In view of the progress now being made in Europe, the question naturally arises, "Why is similar progress not being made in the United States?" The development of processes for the fixation of nitrogen takes years of patient work by skilled chemists, with large funds available to cover the expenses of experimentation and development. In Europe, and particularly in Germany, every encouragement has been given by the government and the experimenters were given every facility and all the funds they needed. Also the urge of absolute necessity during the late war caused them to make redoubled efforts. In this country investigators and pioneers were given no material encouragement or assistance until a very short time before our entry into the war.

Private capital now hesitates to engage in the construction and operation of plants in this country for the fixation of atmospheric nitrogen because of the following:

(a) Doubt as to ability to compete commercially with imports, either of Chili saltpeter or of synthetic nitrates

from the well established industry in Europe, particularly Germany.

(b) Uncertainty as to the market in the United States.

(c) Uncertainty as to the future status of the government-owned plants at Muscle Shoals, particularly the Cyanamid plant.

(d) Incomplete data on the details of operation of the Haber process.

These causes of hesitation will be discussed in the order given above.

PROBABLE PRICE OF IMPORTS

The lessening demand for Chili saltpeter in Europe because of the entry of the synthetic nitrates into the market will probably cause some drop in the price in the effort of the producers to retain their market in this country, and even to make up to some extent for the loss of the European market. The price cannot go much below the pre-war figure, however, for the producer's profit at a market price of $40.00 per ton f. o. b. Chili, was less than $10.00 a ton. Serious labor troubles in the Chilean nitrate fields in recent years have so increased the cost of production that the profit, even at the old rate, is extremely small and leaves no room for price cutting. Of course, the price could be reduced if the export duty imposed by the Chilean government were reduced, but such reduction will meet with bitter opposition, and is possible only in the distant future as a last effort to save the market.

The well established German Synthetic nitrogen industry should very soon have large quantities of fixed nitrogen products available for export. The present rates of exchange particularly favor dumping in this country, and unless the American firms about to engage in the industry

are given artificial protection, they will find it impossible to meet the German prices, at least until the American industry is firmly established.

THE MARKET

The market in this country has hardly been scratched on the surface. The amounts of ammonia and nitric acid used for industrial purposes are increasing steadily. The greatest possible increase is probably in the fertilizer industry. Germany before the war used seven times as much fertilizer per cultivated acre as we do in this country. Since the demand for greater production per acre must be largely met by increased use of fertilizer, and since the only source of fertilizer that can be greatly increased is either imported or artificially fixed nitrates, it is readily seen that the market must show constantly increasing demands.

Despite the numerous predictions made during the war that the bottom would drop out of the nitrate market upon the cessation of hostilities, the price has remained remarkably firm. Even within the last month a further rise in the market price of ammonium sulphate has been recorded.

THE DISPOSITION TO BE MADE OF THE MUSCLE SHOALS PLANTS

The Nitrate Division of the Army has retained the two plants at Muscle Shoals, known as Nitrate Plants No. 1 and No. 2.

Plant No. 1 has a rated capacity of 10,000 tons of ammonia per year. It is designed for operation on the General Chemical Company's principle. This is really a modification of the Haber principle, the principal difference being that the General Chemical Company System uses a pressure of about 100 atmospheres in the ammonia catalysis au-

toclaves, while the Haber system uses 200 atmospheres. Plant No. 1 was built as a war emergency measure, under the full realization that the General Chemical Company's process had not yet been fully developed on a manufacturing scale and that expensive changes in processes and equipment would probably have to be made as more complete knowledge of the most efficient working conditions was obtained. The plant has operated on a small scale for the production of ammonia, but has not operated on a quantity scale. There is no prospect of its getting into quantity production in the near future, as several changes in plant arrangement and equipment are necessary and no funds are available.

The Nitrate Division is, however, continuing experimentation, both on the Haber and the General Chemical Company's systems, with the idea of obtaining all necessary data for the efficient operation of the plant if its operation is decided upon and funds become available. All information received concerning the methods of operation of the German plants is confirmed by experiment. The greatest attention has been devoted to two subjects, the investigation of the action of a large number of possible catalysts, and the securing of a steel that will withstand the extremely high temperatures that are encountered in this process. Recently a satisfactory steel has apparently been obtained and large scale tests are now about to be conducted. The investigation of catalysts is still under way.

Plant No. 2, which was built to operate by the cyanamid process, has a rated capacity of 220,000 tons of cyanamid yearly—the equivalent of about 35,000 tons of ammonia. As the plant was built with the coöperation of the American Cyanamid Company, who have operated a small plant for ten years on the Canadian side of Niagara Falls, compara-

tively few development difficulties had to be overcome, and the entire plant was in actual operation on November 25, 1918, producing ammonium nitrate. Operation was discontinued shortly thereafter, however, because of lack of funds, and because no authority existed for the operation of the plant for the manufacture of nitrates and fertilizers to meet the commercial demand.

The Kahn bill, now before Congress, would appropriate $12,000,000 for the operation of the Muscle Shoals Plant for the supply of commercial fertilizers and nitrates. If this bill is passed it is the intention to operate one-third of plant No. 2, using the different sections of the plant in rotation, so as to keep all parts of the plant in proper condition of upkeep. Two million dollars would be used for repairs and necessary changes and the remaining ten million used as an operating fund. Three-quarters of the production of the plant would be devoted to ammonium sulfate, and the remainder to mixed products, principally ammonium nitrate. The idea in manufacturing nitrate is to keep the ammonia oxidization part of the plant in working order, so that in the event of the sudden necessity arising for the production of nitric acid by the entire plant, the apparatus would be ready, and the personnel familiar with the operations.

It is believed that ammonium sulfate can be delivered by this plant at a cost of $35.00 per ton, with such a rate of profit that a fair interest rate will be given on the $12,000,000 now requested, and a small amount remain over for the gradual paying off of the original $70,000,000 cost of the plant. It is not believed, however, that the plant can be run at a profit on the whole $82,000,000 investment. Inasmuch as there is no chance of obtaining anything like the original cost of the plant if it is sold to any private con-

cern, it seems advisable for the government to undertake the commercial operation of the plant under the terms of the Kahn bill.

While waiting for Congress to decide as to the disposition to be made of the plant, the Nitrate Division is going ahead with experiments looking to the improvements in operation methods of the plant. At present attention is being devoted to the methods of manufacture of the various commercial fertilizers, and of new combinations of nitrogen containing mixtures for use as fertilizers. A process for the development of urea is also being developed. The question of the disposition to be made of the sludge from the cyanamid furnaces is also being investigated. Formerly this sludge has been considered as of no value, and the disposal of 700 tons per day in a flat country like that near Muscle Shoals was a costly operation. Now it is believed that the processes under investigation for the recovery of the 15% of graphite, and the 6% of sodium hydroxide contained in the sludge will pay for the cost of the disposal of the residue and return a good profit besides.

THE PRESENT POSITION OF PRIVATE FIRMS INTERESTED IN THE SUBJECT

The American Nitrogen Products Company is operating the only plant now engaged in the fixation of atmospheric nitrogen in this country. The plant is located near Tacoma, Washington. It is operated on the Birkeland-Eyde arc principle. Power is obtained from the City of Tacoma hydro-electric power plant, using the off-peak load. In this way power is obtained at a rate less than the actual average cost to the city, and yet the arrangement is profitable to the city, because it is a revenue producing use for what would otherwise be practically wasted power. The

company seems to be in good financial condition, and has been making plans for considerable expansion, by the erection of their own power plants and new arc plants in the mountains of British Columbia. Unless they have been able to bring about almost revolutionary increases in economy of the process, however, it is not understood by those not in the company how they hope to operate at a profit in time of peace.

The American Cyanamid Company is, of course, enthusiastic about the cyanamid process. They control the patents on this process. Their enthusiasm does not, however, appear to be leading them to the construction of a plant in this country. It is understood that they have made bids on the cyanamid plant at Muscle Shoals, but that this bid was such a small percentage of the original cost of the plant, as not to indicate very great confidence in their ability to make the operation of the plant a financial success in the face of the competition.

Other companies interested in the subject are naturally inclined to await the outcome of the Kahn bill before going very far in the expenditure of money. It is understood that practically all of them believe that the Haber process offers the greatest prospect of success. The Semet-Solvay Company has already made application for the right to the Haber patents in this country, and it is understood that they have already acquired the General Chemical Company's rights. It seems very probable that this combination will shortly go ahead with the erection of a plant on the Haber principle, regardless of the outcome of the Kahn bill, although they would of course much prefer to see the Kahn bill defeated. This plant will probably be located near Niagara Falls, so as to obtain the great supply of free hydrogen that is now going to waste in the bleaching and alkali industries.

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